IoT4Ag

The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

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YEAR 5

ANNUAL REPORT

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1. PROJECT SUMMARY

OVERVIEW: By 2050, the US population is estimated to grow to 400 million and the world population to 9.7 billion. Current agricultural practices account for 70% of global water use, energy use is one of the largest farm costs, and inefficient agrochemical use is altering Earth's ecosystems. With finite arable land, water, and energy resources and with the negative impacts of climate change, ensuring food, energy, and water security will require new technologies to improve the efficiency of food production, create sustainable approaches to supply energy, and prevent water scarcity. While the concept of precision agriculture has existed for 30 years, the exponential growth in information technology and data science and the reduction in their cost are setting the stage for the next revolution in agricultural practices. IoT4Ag unites an interdisciplinary cadre of faculty and students from the University of Pennsylvania, Purdue University, the University of California-Merced, and the University of Florida, and in evaluation and assessment, from the Arizona State University, with partners in education, government, and industry. The IoT4Ag mission is to create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

INTELLECTUAL MERIT: IoT4Ag is creating integrated sense-communication-response systems to transform agriculture in two Testbeds: Integrated Solutions for Precision Farming of Row and Tree Crops. IoT4Ag is structured into three thrusts that vertically integrate fundamental knowledge and technology from different disciplines and that are horizontally integrated to achieve next generation engineered systems for agriculture. Thrust 1–Agricultural sensor systems is designing and manufacturing resilient, networked, intelligent sensor-robotic systems that monitor the state of plant and soil health over extended areas and that will enable the Center to uncover how the complex system of abiotic and biotic variables affect crop yield and resilience. Thrust 2–Communication and energy systems is enabling advanced approaches for powering IoT devices and robots in the field and for Ag-specific data communication from heterogeneous platforms of sensors, robots, and farming equipment. Thrust 3–Agricultural response systems is creating and deploying smart response systems for precision agriculture that are built on digital twins of row and tree crops driven by artificial intelligence and decision-based models, and are used to establish a human-centered interface for farmers to intelligently and cost-effectively manage their fields. IoT4Ag Joint Ops bring Center technologies together into systems to address significant challenges in agricultural crop yield and resiliency and in sustainable farm management.

BROADER IMPACTS: IoT4Ag unites in research, education, inclusion, and innovation a convergence of expertise in agronomy, agricultural engineering and economics, and environmental and social sciences and in the science and engineering of physical and cyber systems. The IoT4Ag Empowering People Portfolio (**IoT4Ag E^3**): EXCITE - Tech Meets Ag, EDUCATE for an Inclusive World, and ENABLE Professional Advancement serves diverse participants, from pre-college, community college, and university students to agricultural professionals across the US. **IoT4Ag E^3** programs prepare participants to have strong science and engineering knowledge and to be able to discover, innovate, translate, and practice precision agriculture solutions. The Center's innovation ecosystem is a vibrant network of academic, industry, investment, and government partners and the end-user farming community working collaboratively to ensure IoT4Ag practices and technologies are rapidly translated into commercial products and build the future of precision agriculture.

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2. PARTICIPANT TABLES

ERCWEB TABLE 1: Academic Institutions				
Academic Institution	**Institution Type**	**City**	**State**	**Country**
University of Pennsylvania	Lead Institution	Philadelphia	Pennsylvania	United States of America
4-H Science and Adventure Camp	Domestic Partner	West Lafayette	Indiana	United States of America
AgrAbility	Domestic Partner	West Lafayette	Indiana	United States of America
Arizona State University	Domestic Partner	Tempe	Arizona	United States of America
BobCat Academy	Domestic Partner	Marshalltown	Iowa	United States of America
Cade Museum for Creativity and Invention	Domestic Partner	Gainesville	Florida	United States of America
California Polytechnic State University San Luis Obispo	Domestic Partner	San Luis Obispo	California	United States of America
CalTeach	Domestic Partner	Berkeley	California	United States of America
Center for Information Technology Research in the Interest of Society (CITRIS)	Domestic Partner	Merced	California	United States of America
Community Alliance of Family Farmers	Domestic Partner	Madeira	California	United States of America
Deaf Kids Code	Domestic Partner	West Lafayette	Indiana	United States of America
Future Farmers of America	Domestic Partner	Indianapolis	Indiana	United States of America
Grinnell College	Domestic Partner	Grinnell	Iowa	United States of America
Hamilton West High School	Domestic Partner	Philadelphia	Pennsylvania	United States of America
Illinois Institute of Technology	Domestic Partner	Chicago	Illinois	United States of America
Ivy Tech Community College of Indiana	Domestic Partner	Lawrenceburg	Indiana	United States of America
Kensington High School	Domestic Partner	Philadelphia	Pennsylvania	United States of America
Lankenau Environmental Science High School	Domestic Partner	Philadelphia	Pennsylvania	United States of America
Lower Merion High School	Domestic Partner	Philadelphia	Pennsylvania	United States of America

Academic Institution	Institution Type	City	State	Country
Merced College	Domestic Partner	Merced	California	United States of America
Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS)	Domestic Partner	Atlanta	Georgia	United States of America
Morris Arboretum	Domestic Partner	Philadelphia	Pennsylvania	United States of America
National Agriculture in the Classroom	Domestic Partner	Gainesville	Florida	United States of America
North Carolina State University at Raleigh	Domestic Partner	Raleigh	North Carolina	United States of America
Northeastern University	Domestic Partner	Boston	Massachusetts	United States of America
Northwestern University	Domestic Partner	Evanston	Illinois	United States of America
Pennsylvania Agriculture Cross-Sector Collaborative	Domestic Partner	Harrisburg	Pennsylvania	United States of America
Pennsylvania State University-Main Campus	Domestic Partner	University Park	Pennsylvania	United States of America
Princeton University	Domestic Partner	Princeton	New Jersey	United States of America
Purdue University	Domestic Partner	West Lafayette	Indiana	United States of America
Santa Clara University	Domestic Partner	Santa Clara	California	United States of America
Santa Fe College	Domestic Partner	Gainesville	Florida	United States of America
Science Leadership Academy at Beeber	Domestic Partner	Philadelphia	Pennsylvania	United States of America
Stevens Institute of Technology	Domestic Partner	Hoboken	New Jersey	United States of America
Student Science Training Program	Domestic Partner	Gainesville	Florida	United States of America
Swarthmore College	Domestic Partner	Swarthmore	Pennsylvania	United States of America
Syracuse University	Domestic Partner	Syracuse	New York	United States of America
The University of Texas at Dallas	Domestic Partner	Dallas	Texas	United States of America
The University of Texas at El Paso	Domestic Partner	El Paso	Texas	United States of America
Tuskegee University	Domestic Partner	Tuskegee	Alabama	United States of America
University of California, Merced	Domestic Partner	Merced	California	United States of America

Academic Institution	Institution Type	City	State	Country
University of Florida	Domestic Partner	Gainesville	Florida	United States of America
University of Illinois at Urbana Champaign	Domestic Partner	Champaign	Illinois	United States of America
University of Maryland Baltimore County	Domestic Partner	Baltimore	Maryland	United States of America
University of Maryland Eastern Shore	Domestic Partner	Princess Anne	Maryland	United States of America
University of Pittsburgh	Domestic Partner	Pittsburgh	Pennsylvania	United States of America
University of Puerto Rico at Humacao	Domestic Partner	Humacao	Puerto Rico	United States of America
University of Tennessee Martin	Domestic Partner	Martin	Tennessee	United States of America
University of Texas at Austin	Domestic Partner	Austin	Texas	United States of America
Villanova University	Domestic Partner	Villanova	Pennsylvania	United States of America
W.B. Saul High School of Agriculture	Domestic Partner	Philadelphia	Pennsylvania	United States of America
Walt Disney World	Domestic Partner	Lake Buena Vista	Florida	United States of America

ERCWEB TABLE 2: Leadership Team				
Personnel Type	**Name**	**Title**	**Department**	**Academic Institution**
Director	David P. Arnold	George Kirkland Engineering Leadership Professor	Electrical and Computer Engineering	University of Florida
Director	David J. Cappelleri	Associate Professor	Mechanical Engineering	Purdue University
Director	Stefano Carpin	Professor	Computer Science and Engineering	University of California, Merced
Director	Cherie Kagan	Stephen J Angello Professor	Electrical and Systems Engineering	University of Pennsylvania
Director	Kevin T. Turner	Professor and Chair	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Research Thrust Leader	Carlos Messina	Professor	Horticultural Sciences	University of Florida
Research Thrust Leader	Dennis R. Buckmaster	Professor of ABE | Dean's Fellow for Digital Agriculture	Agricultural & Biological Engineering	Purdue University
Research Thrust Leader	David J. Love	Nick Trbovich Professor of Electrical and Computer Engineering	Electrical and Computing Engineering	Purdue University
Research Thrust Leader	Troy Olsson	Associate Professor	Electrical and Systems Engineering	University of Pennsylvania
Research Thrust Leader	Melba Crawford	Professor	Civil Engineering	Purdue University
Research Thrust Leader	Reza Ehsani	Professor	Mechanical Engineering	University of California, Merced
Research Thrust Leader	Mark G. Allen	Professor	Electrical and Systems Engineering	University of Pennsylvania

Personnel Type	Name	Title	Department	Academic Institution
Engineering Workforce Development Program Leader	Ian M. Small	Associate Professor	Plant Pathology	University of Florida
Engineering Workforce Development Program Leader	Sue Ann Bidstrup-Allen	Professor and Associate Dean	Chemical and Biomolecular Engineering	University of Pennsylvania
Engineering Workforce Development Program Leader	Kristin Field	Director of Education and Inclusivity	Engineering and Applied Science	University of Pennsylvania
Administrative Director	Robert A. Brier	Managing Director	Engineering and Applied Science	University of Pennsylvania
Staff (Leadership)	Steven S. Weiner	Sr. Director, Innovation & Technology	Engineering and Applied Science	University of Pennsylvania
Staff (Leadership)	Domonique McClendon	Administrative and Outreach Coordinator	Electrical and Computer Engineering	University of Pennsylvania
Student Leader	Jun Xu	Doctoral Student	Electrical and Computer Engineering	University of Pennsylvania
Student Leader	Sneha Jun	Doctoral Student	Electrical and Computer Engineering	Purdue University
Student Leader	Kamila Dilmurat	Postdoctoral Fellow	Earth and Environmental Sciences	University of California, Merced
Student Leader	Samiul Basir	Doctoral Student	Agricultural & Biological Engineering	Purdue University
Student Leader	Vernon S. Crasto	Doctoral Student	Electrical and Computer Engineering	University of Florida
Student Leader	Anna Hampton	Doctoral Student	Electrical and Computer Engineering	University of Florida

Personnel Type	Name	Title	Department	Academic Institution
Student Leader	Harsh Pathak	Doctoral Student	Agricultural & Biological Engineering	Purdue University
Student Leader	Shobhita Kramadhati	Graduate Research Assistant	Electrical and Systems Engineering	University of Pennsylvania
Student Leader	Mehrad Mortazavi	Doctoral Student	Mechanical Engineering	University of California, Merced
Diversity and Culture of Inclusion Program Leader	Paulo Arratia	Professor	Mechanical Engineering & Applied Mechanics	University of Pennsylvania
Diversity and Culture of Inclusion Program Leader	Melanie L. Yeo	Assistant Professor	Management of Complex Systems	University of California, Merced

ERCWEB TABLE 3: Research Thrust Participants			
Personnel Type	**Name**	**Department**	**Academic Institution**
Engineering Workforce Development			
Thrust Leader	Sue Ann Bidstrup-Allen	Chemical and Biomolecular Engineering	University of Pennsylvania
Senior Faculty	Sebastian Galindo	Electrical and Computer Engineering	University of Florida
Junior Faculty	Kathryn Stofer	Agricultural Education and Communication	University of Florida
Doctoral Student	Caroline Nickerson	Agricultural Education and Communication	University of Florida
Masters Student	Shiala M. Naranjo	Department of Forestry	University of Florida
Thrust 1: Agricultural Sensors Systems			
Thrust Leader	Reza Ehsani	Mechanical Engineering	University of California, Merced
Director	Cherie Kagan	Electrical and Systems Engineering	University of Pennsylvania
Director	David J. Cappelleri	Mechanical Engineering	Purdue University
Director	David P. Arnold	Electrical and Computer Engineering	University of Florida
Director	Kevin T. Turner	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Director	Stefano Carpin	Computer Science and Engineering	University of California, Merced
Research Thrust Leader	Carlos Messina	Horticultural Sciences	University of Florida
Research Thrust Leader	Dennis R. Buckmaster	Agricultural & Biological Engineering	Purdue University
Research Thrust Leader	Mark G. Allen	Electrical and Systems Engineering	University of Pennsylvania
Research Thrust Leader	Melba Crawford	Civil Engineering	Purdue University
Research Thrust Leader	Troy Olsson	Electrical and Systems Engineering	University of Pennsylvania
Engineering Workforce Development Program Leader	Ian M. Small	Plant Pathology	University of Florida
Engineering Workforce Development Program Leader	Sue Ann Bidstrup-Allen	Chemical and Biomolecular Engineering	University of Pennsylvania
Student Leader	Anna Hampton	Electrical and Computer Engineering	University of Florida
Student Leader	Harsh Pathak	Agricultural & Biological Engineering	Purdue University
Student Leader	Jun Xu	Electrical and Computer Engineering	University of Pennsylvania
Student Leader	Kamila Dilmurat	Earth and Environmental Sciences	University of California, Merced

Personnel Type	Name	Department	Academic Institution
Student Leader	Mehrad Mortazavi	Mechanical Engineering	University of California, Merced
Student Leader	Shobhita Kramadhati	Electrical and Systems Engineering	University of Pennsylvania
Diversity and Culture of Inclusion Program Leader	Paulo Arratia	Mechanical Engineering & Applied Mechanics	University of Pennsylvania
Senior Faculty	Alejandro Ribeiro	Electrical and System Engineering	University of Pennsylvania
Senior Faculty	Alina Zare	Electrical and Computer Engineering	University of Florida
Senior Faculty	Brent Sumerlin	Chemistry	University of Florida
Senior Faculty	Erin Hestir	Civil & Environmental Engineering	University of California, Merced
Senior Faculty	James Krogmeier	Electrical and Computer Engineering	Purdue University
Senior Faculty	Tony J. Vyn	Agronomy	Purdue University
Senior Faculty	Vijay Kumar	Engineering and Applied Science	University of Pennsylvania
Senior Faculty	William Eisenstadt	Electrical and Computer Engineering	University of Florida
Junior Faculty	Daniel Quinn	Agriculture and Natural Resources	Purdue University
Junior Faculty	Pratik Chaudhari	Electrical and Systems Engineering	University of Pennsylvania
Junior Faculty	Sanjeev Koppal	Electrical and Computer Engineering	University of Florida
Staff	Alex Zhou	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Junior Faculty	Vivek Sharma	Agricultural and Biological Engineering	University of Florida
Staff	Arash Toudeshki	Mechanical Engineering	University of California, Merced
Staff	Jiuzhou Lei	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Staff	Trishna Tiwari	Horticultural Sciences	University of Florida
Staff	Zihuan Teng	Plant Pathology	University of Florida
Postdoc	Akhila Mallavarapu	Electrical and Computer Engineering	University of Pennsylvania
Postdoc	Anamika Singh	Electrical and Systems Engineering	University of Pennsylvania
Postdoc	Ignacio Hisse	Horticultural Sciences	University of Florida
Postdoc	Saurav Agarwal	Computer Science	University of Pennsylvania
Postdoc	Shravan Pradeep	Mechanics, Earth & Environmental Science	University of Pennsylvania
Postdoc	Varun Murali	Mechanical Engineering and Applied Mechanics.	University of Pennsylvania
Doctoral Student	Aarya Deb	Mechanical Engineering	Purdue University

Personnel Type	Name	Department	Academic Institution
Doctoral Student	Alice K. Li	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Ana Gabriela Morales-Ona	Agronomy	Purdue University
Doctoral Student	Andrew D. Balmos	College of Agriculture	Purdue University
Doctoral Student	Anne-Marie Zaccarin	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Azar Alizadeh	Electrical Engineering and Computer Science	University of California, Merced
Doctoral Student	Azin Shamshirgaran	Computer and Information Science	University of California, Merced
Doctoral Student	Blanch Khouri-Sader	Chemistry	University of Florida
Doctoral Student	Chavez Lawrence	Engineering and Applied Sciences	University of Pennsylvania
Doctoral Student	Claudia E. Aviles Toledo	Geomatics / Agriculture	Purdue University
Doctoral Student	Damian Owerko	Electrical and Computer Engineering	University of Pennsylvania
Doctoral Student	Dexter Ong	Computer and Information Science	University of Pennsylvania
Doctoral Student	Elizabeth Schell	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Emily Beeman	Materials Science and Engineering	University of Pennsylvania
Doctoral Student	Fatemeh Maghsood	Agricultural and Biological Engineering	University of Florida
Doctoral Student	Fernando Cladera Ojeda	Computer and Information Science	University of Pennsylvania
Doctoral Student	Frederic Vatnsdal	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Gokulanand Iyer	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Jackson Arnold	Electrical and Computer Engineering	University of Florida
Doctoral Student	Jacob Nesslage	School of Engineering	University of California, Merced
Doctoral Student	Jingwen Zhang	Engineering and Applied Science	University of Pennsylvania
Doctoral Student	Justin Pitts	Agronomy and Electrical & Computer Engineering	University of Florida
Doctoral Student	Karoll Quijano	Civil Engineering	Purdue University
Doctoral Student	Khaled N. Hamad	Electrical and Computer Engineering	University of Florida
Doctoral Student	Kitae Kim	Mechanical Engineering	Purdue University
Doctoral Student	Lorenzo Booth	School of Engineering	University of California, Merced
Doctoral Student	Makyla Boyd	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Malakhi Hopkins	Engineering and Applied Science	University of Pennsylvania

Personnel Type	Name	Department	Academic Institution
Doctoral Student	Marcos Zuzuarregui	Electrical and Computer Engineering	University of California, Merced
Doctoral Student	Melanie Cabrera	Environmental Horticulture	University of Florida
Doctoral Student	Michael Machold	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Rebecca L. Barocco	College of Agricultural and Life Sciences	University of Florida
Doctoral Student	Richeek Das	Computer and Information Science	University of Pennsylvania
Doctoral Student	Senior Adepoju	Environmental Systems	University of California, Merced
Doctoral Student	Wei Liu	Electrical and Computer Engineering	Purdue University
Doctoral Student	Xu Liu	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Yanghuang Huang	Chemical Engineering	University of Pennsylvania
Doctoral Student	Yifei Shao	Computer and Information Science	University of Pennsylvania
Masters Student	Aakash Agarwal	Electrical and Systems Engineering	University of Pennsylvania
Masters Student	Ankit Prabhu	Engineering and Applied Science	University of Pennsylvania
Masters Student	Brendan J. Hanson	Agronomy	Purdue University
Masters Student	Derek Cheng	Robotics	University of Pennsylvania
Masters Student	Erick Oliva	Agronomy	Purdue University
Masters Student	Gunnar Fandrich	Electrical and Computer Engineering	University of Florida
Masters Student	Haoxuan Lyu	Electrical and Systems Engineering	University of Pennsylvania
Masters Student	Kai Lu	Engineering and Applied Science	University of Pennsylvania
Masters Student	Lujie Cai	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Masters Student	Pratyush Mallick	Electrical and Systems Engineering	University of Pennsylvania
Undergraduate Student	Abdinajib Mohamed	Electrical and Systems Engineering	University of Pennsylvania
Undergraduate Student	Benjamin Jenness	Agriculture	Purdue University
Undergraduate Student	Brian Huang	Mechanical Engineering	Purdue University
Undergraduate Student	Cosme Cruz	Mechanical Engineering	University of California, Merced
Undergraduate Student	David Moore	Electrical and Computer Engineering	University of Florida
Undergraduate Student	Jovanie Ruiz	Mechanical Engineering	University of California, Merced
Undergraduate Student	Kianna Ng	Computer Science and Engineering	University of California, Merced

Personnel Type	Name	Department	Academic Institution
Undergraduate Student	Lorenzo Stewart	Computer Science and Engineering	University of California, Merced
Undergraduate Student	Maria Contreras	Civil & Environmental Engineering	University of California, Merced
Undergraduate Student	Michael Montgomery	Aviation and Transportation Technology	Purdue University
Undergraduate Student	Morgan Malone	Anthropology	University of California, Merced
Undergraduate Student	Sabrina Zhang	The Wharton School	University of Pennsylvania
Undergraduate Student	Sean MacDonald	Mechanical Engineering	Purdue University
Undergraduate Student	Trevor Free	Electrical and Computer Engineering	University of Florida
Undergraduate Student	Yiwei Bian	Electrical and Computer Engineering	University of Florida
REU Student (Center Funding)	Alan Chen	Mechanical Engineering	Santa Clara University
REU Student (Center Funding)	Anika Guin	Engineering and Computer Science	The University of Texas at Dallas
REU Student (Center Funding)	Claire Petersen	N/A	Northwestern University
REU Student (Center Funding)	Edward Fluker	Electrical and Computer Engineering	Syracuse University
REU Student (Center Funding)	Ismael Luna	Electrical and Computer Engineering	The University of Texas at El Paso
REU Student (Center Funding)	Mia Holland	N/A	Swarthmore College
REU Student (Center Funding)	Samarth Chopra	Electrical and Computer Engineering	University of Pittsburgh
REU Student (Center Funding)	Taylor Vaughan	Chemistry and Biochemistry	California Polytechnic State University San Luis Obispo
REU Student (Center Funding)	Tyler Inkeles	Chemistry	California Polytechnic State University San Luis Obispo
REU Student (NSF REU Site Award)	Abhiram Pulavarthi	Electrical and Systems Engineering	Northeastern University
REU Student (NSF REU Site Award)	Manasa Sripati	Mechanical Engineering and Applied Mechanics	University of Texas at Austin
REU Student (Other NSF Supplemental Funding)	Alexandru Platon	Materials Science and Engineering	University of Pennsylvania
REU Student (Other NSF Supplemental Funding)	Rohan Mody	Chemistry	Illinois Institute of Technology
Teacher (RET)	Eric Cruz	Kensington High School	Kensington High School
Teacher (RET)	Jacob Turko	W.B. Saul High School of Agriculture	W.B. Saul High School of Agriculture
Thrust 2: Communication and Energy Systems			
Thrust Leader	Mark G. Allen	Electrical and Systems Engineering	University of Pennsylvania
Director	Cherie Kagan	Electrical and Systems Engineering	University of Pennsylvania

Personnel Type	Name	Department	Academic Institution
Director	David J. Cappelleri	Mechanical Engineering	Purdue University
Director	David P. Arnold	Electrical and Computer Engineering	University of Florida
Director	Kevin T. Turner	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Director	Stefano Carpin	Computer Science and Engineering	University of California, Merced
Research Thrust Leader	David J. Love	Electrical and Computing Engineering	Purdue University
Research Thrust Leader	Dennis R. Buckmaster	Agricultural & Biological Engineering	Purdue University
Research Thrust Leader	Melba Crawford	Civil Engineering	Purdue University
Research Thrust Leader	Troy Olsson	Electrical and Systems Engineering	University of Pennsylvania
Engineering Workforce Development Program Leader	Ian M. Small	Plant Pathology	University of Florida
Engineering Workforce Development Program Leader	Sue Ann Bidstrup-Allen	Chemical and Biomolecular Engineering	University of Pennsylvania
Student Leader	Jun Xu	Electrical and Computer Engineering	University of Pennsylvania
Student Leader	Samiul Basir	Agricultural & Biological Engineering	Purdue University
Student Leader	Vernon S. Crasto	Electrical and Computer Engineering	University of Florida
Diversity and Culture of Inclusion Program Leader	Paulo Arratia	Mechanical Engineering & Applied Mechanics	University of Pennsylvania
Senior Faculty	Alejandro Ribeiro	Electrical and System Engineering	University of Pennsylvania
Senior Faculty	James Krogmeier	Electrical and Computer Engineering	Purdue University
Senior Faculty	Tony J. Vyn	Agronomy	Purdue University
Senior Faculty	Vijay Kumar	Engineering and Applied Science	University of Pennsylvania
Senior Faculty	William Eisenstadt	Electrical and Computer Engineering	University of Florida
Junior Faculty	Daniel Quinn	Agriculture and Natural Resources	Purdue University
Postdoc	Anamika Singh	Electrical and Systems Engineering	University of Pennsylvania
Postdoc	Joseph Iboyi	North Florida Research and Education Center	University of Florida
Postdoc	Saurav Agarwal	Computer Science	University of Pennsylvania
Doctoral Student	Aarya Deb	Mechanical Engineering	Purdue University
Doctoral Student	Andrew D. Balmos	College of Agriculture	Purdue University
Doctoral Student	Anne-Marie Zaccarin	Electrical and Systems Engineering	University of Pennsylvania

Personnel Type	Name	Department	Academic Institution
Doctoral Student	Ashwin Natraj Arun	Electrical and Computer Engineering Department	Purdue University
Doctoral Student	Byunghyun Lee	Electrical and Computer Engineering	Purdue University
Doctoral Student	Claudia E. Aviles Toledo	Geomatics / Agriculture	Purdue University
Doctoral Student	Damian Owerko	Electrical and Computer Engineering	University of Pennsylvania
Doctoral Student	Elizabeth Schell	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Emily Beeman	Materials Science and Engineering	University of Pennsylvania
Doctoral Student	Fabio A. Castiblanco Rubio	Electrical and Computer Engineering	Purdue University
Doctoral Student	Frederic Vatnsdal	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Jacqueline R. Malayter	Electrical and Computer Engineering	Purdue University
Doctoral Student	Jingwen Zhang	Engineering and Applied Science	University of Pennsylvania
Doctoral Student	Kitae Kim	Mechanical Engineering	Purdue University
Doctoral Student	Makyla Boyd	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Michael Machold	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Rebecca L. Barocco	College of Agricultural and Life Sciences	University of Florida
Doctoral Student	Xu Liu	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Yanghuang Huang	Chemical Engineering	University of Pennsylvania
Masters Student	Aakash Agarwal	Electrical and Systems Engineering	University of Pennsylvania
Masters Student	Brendan J. Hanson	Agronomy	Purdue University
Masters Student	Erick Oliva	Agronomy	Purdue University
Masters Student	Haoxuan Lyu	Electrical and Systems Engineering	University of Pennsylvania
Masters Student	Pratyush Mallick	Electrical and Systems Engineering	University of Pennsylvania
Undergraduate Student	Matthew Stormant	Electrical and Computer Engineering	University of Florida
Undergraduate Student	Sabrina Zhang	The Wharton School	University of Pennsylvania
Undergraduate Student	Sean MacDonald	Mechanical Engineering	Purdue University
Undergraduate Student	Trevor Free	Electrical and Computer Engineering	University of Florida
Undergraduate Student	Yiwei Bian	Electrical and Computer Engineering	University of Florida
REU Student (Center Funding)	Alan Chen	Mechanical Engineering	Santa Clara University

Personnel Type	Name	Department	Academic Institution
REU Student (Center Funding)	Claire Petersen	N/A	Northwestern University
REU Student (Center Funding)	Edward Fluker	Electrical and Computer Engineering	Syracuse University
REU Student (Center Funding)	Ismael Luna	Electrical and Computer Engineering	The University of Texas at El Paso
REU Student (NSF REU Site Award)	Abhiram Pulavarthi	Electrical and Systems Engineering	Northeastern University
REU Student (NSF REU Site Award)	Manasa Sripati	Mechanical Engineering and Applied Mechanics	University of Texas at Austin
REU Student (Other NSF Supplemental Funding)	Rohan Mody	Chemistry	Illinois Institute of Technology
Teacher (RET)	Eric Cruz	Kensington High School	Kensington High School
Thrust 3: Agricultural Response Systems			
Thrust Leader	Dennis R. Buckmaster	Agricultural & Biological Engineering	Purdue University
Director	Cherie Kagan	Electrical and Systems Engineering	University of Pennsylvania
Director	David J. Cappelleri	Mechanical Engineering	Purdue University
Director	David P. Arnold	Electrical and Computer Engineering	University of Florida
Director	Stefano Carpin	Computer Science and Engineering	University of California, Merced
Research Thrust Leader	Carlos Messina	Horticultural Sciences	University of Florida
Research Thrust Leader	David J. Love	Electrical and Computing Engineering	Purdue University
Research Thrust Leader	Melba Crawford	Civil Engineering	Purdue University
Research Thrust Leader	Reza Ehsani	Mechanical Engineering	University of California, Merced
Engineering Workforce Development Program Leader	Ian M. Small	Plant Pathology	University of Florida
Student Leader	Anna Hampton	Electrical and Computer Engineering	University of Florida
Student Leader	Harsh Pathak	Agricultural & Biological Engineering	Purdue University
Student Leader	Kamila Dilmurat	Earth and Environmental Sciences	University of California, Merced
Student Leader	Mehrad Mortazavi	Mechanical Engineering	University of California, Merced
Student Leader	Samiul Basir	Agricultural & Biological Engineering	Purdue University
Student Leader	Shobhita Kramadhati	Electrical and Systems Engineering	University of Pennsylvania
Diversity and Culture of Inclusion Program Leader	Melanie L. Yeo	Management of Complex Systems	University of California, Merced

Personnel Type	Name	Department	Academic Institution
Senior Faculty	Alina Zare	Electrical and Computer Engineering	University of Florida
Senior Faculty	Brent Sumerlin	Chemistry	University of Florida
Senior Faculty	Catherine Keske	Management, Innovation, Sustainability, Technology	University of California, Merced
Senior Faculty	Erin Hestir	Civil & Environmental Engineering	University of California, Merced
Senior Faculty	James Krogmeier	Electrical and Computer Engineering	Purdue University
Senior Faculty	Sebastian Galindo	Electrical and Computer Engineering	University of Florida
Senior Faculty	Vijay Kumar	Engineering and Applied Science	University of Pennsylvania
Senior Faculty	William Eisenstadt	Electrical and Computer Engineering	University of Florida
Junior Faculty	Daniel Quinn	Agriculture and Natural Resources	Purdue University
Junior Faculty	Kathryn Stofer	Agricultural Education and Communication	University of Florida
Junior Faculty	Pratik Chaudhari	Electrical and Systems Engineering	University of Pennsylvania
Junior Faculty	Sanjeev Koppal	Electrical and Computer Engineering	University of Florida
Junior Faculty	Vivek Sharma	Agricultural and Biological Engineering	University of Florida
Staff	Alex Zhou	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Staff	Arash Toudeshki	Mechanical Engineering	University of California, Merced
Staff	Jiuzhou Lei	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Staff	Trishna Tiwari	Horticultural Sciences	University of Florida
Staff	Zihuan Teng	Plant Pathology	University of Florida
Postdoc	Akhila Mallavarapu	Electrical and Computer Engineering	University of Pennsylvania
Postdoc	Ignacio Hisse	Horticultural Sciences	University of Florida
Postdoc	Joseph Iboyi	North Florida Research and Education Center	University of Florida
Postdoc	Varun Murali	Mechanical Engineering and Applied Mechanics.	University of Pennsylvania
Doctoral Student	Aarya Deb	Mechanical Engineering	Purdue University
Doctoral Student	Alice K. Li	Electrical and Systems Engineering	University of Pennsylvania
Doctoral Student	Ana Gabriela Morales-Ona	Agronomy	Purdue University
Doctoral Student	Andrew D. Balmos	College of Agriculture	Purdue University
Doctoral Student	Ashwin Natraj Arun	Electrical and Computer Engineering Department	Purdue University

Personnel Type	Name	Department	Academic Institution
Doctoral Student	Azar Alizadeh	Electrical Engineering and Computer Science	University of California, Merced
Doctoral Student	Azin Shamshirgaran	Computer and Information Science	University of California, Merced
Doctoral Student	Blanch Khouri-Sader	Chemistry	University of Florida
Doctoral Student	Byunghyun Lee	Electrical and Computer Engineering	Purdue University
Doctoral Student	Caroline Nickerson	Agricultural Education and Communication	University of Florida
Doctoral Student	Chavez Lawrence	Engineering and Applied Sciences	University of Pennsylvania
Doctoral Student	Claudia E. Aviles Toledo	Geomatics / Agriculture	Purdue University
Doctoral Student	Dexter Ong	Computer and Information Science	University of Pennsylvania
Doctoral Student	Fabio A. Castiblanco Rubio	Electrical and Computer Engineering	Purdue University
Doctoral Student	Fatemeh Maghsood	Agricultural and Biological Engineering	University of Florida
Doctoral Student	Fernando Cladera Ojeda	Computer and Information Science	University of Pennsylvania
Doctoral Student	Jackson Arnold	Electrical and Computer Engineering	University of Florida
Doctoral Student	Jacob Nesslage	School of Engineering	University of California, Merced
Doctoral Student	Jacqueline R. Malayter	Electrical and Computer Engineering	Purdue University
Doctoral Student	Justin Pitts	Agronomy and Electrical & Computer Engineering	University of Florida
Doctoral Student	Karoll Quijano	Civil Engineering	Purdue University
Doctoral Student	Khaled N. Hamad	Electrical and Computer Engineering	University of Florida
Doctoral Student	Kitae Kim	Mechanical Engineering	Purdue University
Doctoral Student	Lorenzo Booth	School of Engineering	University of California, Merced
Doctoral Student	Malakhi Hopkins	Engineering and Applied Science	University of Pennsylvania
Doctoral Student	Marcos Zuzuarregui	Electrical and Computer Engineering	University of California, Merced
Doctoral Student	Melanie Cabrera	Environmental Horticulture	University of Florida
Doctoral Student	Rebecca L. Barocco	College of Agricultural and Life Sciences	University of Florida
Doctoral Student	Richeek Das	Computer and Information Science	University of Pennsylvania
Doctoral Student	Senior Adepoju	Environmental Systems	University of California, Merced
Doctoral Student	Steven Sun	Management of Complex Systems	University of California, Merced
Doctoral Student	Wei Liu	Electrical and Computer Engineering	Purdue University

Personnel Type	Name	Department	Academic Institution
Doctoral Student	Xu Liu	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Doctoral Student	Yifei Shao	Computer and Information Science	University of Pennsylvania
Masters Student	Ankit Prabhu	Engineering and Applied Science	University of Pennsylvania
Masters Student	Derek Cheng	Robotics	University of Pennsylvania
Masters Student	Erick Oliva	Agronomy	Purdue University
Masters Student	Gunnar Fandrich	Electrical and Computer Engineering	University of Florida
Masters Student	Shiala M. Naranjo	Department of Forestry	University of Florida
Undergraduate Student	Benjamin Jenness	Agriculture	Purdue University
Undergraduate Student	Calvin Hoang	Management of Complex Systems	University of California, Merced
Undergraduate Student	Cosme Cruz	Mechanical Engineering	University of California, Merced
Undergraduate Student	David Moore	Electrical and Computer Engineering	University of Florida
Undergraduate Student	Jovanie Ruiz	Mechanical Engineering	University of California, Merced
Undergraduate Student	Kianna Ng	Computer Science and Engineering	University of California, Merced
Undergraduate Student	Lorenzo Stewart	Computer Science and Engineering	University of California, Merced
Undergraduate Student	Maria Contreras	Civil & Environmental Engineering	University of California, Merced
Undergraduate Student	Michael Montgomery	Aviation and Transportation Technology	Purdue University
Undergraduate Student	Morgan Malone	Anthropology	University of California, Merced
REU Student (Center Funding)	Anika Guin	Engineering and Computer Science	The University of Texas at Dallas
REU Student (Center Funding)	Samarth Chopra	Electrical and Computer Engineering	University of Pittsburgh
REU Student (Center Funding)	Taylor Vaughan	Chemistry and Biochemistry	California Polytechnic State University San Luis Obispo
REU Student (Center Funding)	Tyler Inkeles	Chemistry	California Polytechnic State University San Luis Obispo

ERCWEB TABLE 4: ERC Partners				
ERC Partner Name	**ERC Partner Type**	**Country**	**City**	**State**
4-H Science and Adventure Camp	Collaborating Institution	United States of America	West Lafayette	Indiana
AgrAbility	Collaborating Institution	United States of America	West Lafayette	Indiana
AgriBugs, LLC	Industrial/Practitioner Member	United States of America	Tallahassee	Florida
AgSensor Solutions	Industrial/Practitioner Member	United States of America	Longview	Texas
Aigen	Industrial/Practitioner Member	United States of America	Kirkland	Washington
Almond Board of California	Innovation Partner	United States of America	Modesto	California
American Peanut Council	Innovation Partner	United States of America	Alexandria	Virginia
Arizona State University	Collaborating Institution	United States of America	Tempe	Arizona
Augean Robotics, Inc. (Burro)	Industrial/Practitioner Member	United States of America	Philadelphia	Pennsylvania
Bayer CropScience, LP	Industrial/Practitioner Member	United States of America	St. Louis	Missouri
Ben Franklin Technology Partners Southeastern PA	Innovation Partner	United States of America	Philadelphia	Pennsylvania
BobCat Academy	Pre-college Partner	United States of America	Marshalltown	Iowa
Cade Museum for Creativity and Invention	Pre-college Partner	United States of America	Gainesville	Florida
California Department of Food & Agriculture	Innovation Partner	United States of America	Sacramento	California
California Polytechnic State University San Luis Obispo	Non-ERC Institution Providing REU Students	United States of America	San Luis Obispo	California
CalTeach	Collaborating Institution	United States of America	Berkeley	California
Center for Information Technology Research in the Interest of Society (CITRIS)	Collaborating Institution	United States of America	Merced	California
Community Alliance of Family Farmers	Collaborating Institution	United States of America	Madeira	California

ERC Partner Name	ERC Partner Type	Country	City	State
Corteva (Pioneer Hi-Bred International)	Industrial/Practitioner Member	United States of America	Johnston	Iowa
Cotton Incorporated	Innovation Partner	United States of America	Cary	North Carolina
Deaf Kids Code	Collaborating Institution	United States of America	West Lafayette	Indiana
Deere and Co.	Industrial/Practitioner Member	United States of America	Moline	Illinois
Digital Divide Data Ventures LLC	Innovation Partner	United States of America	New York	New York
FixPosition Ag	Industrial/Practitioner Member	Switzerland	Schlieren	
Florida Dept of Agriculture and Consumer Services	Innovation Partner	United States of America	Tallahassee	Florida
FMC Corporation	Industrial/Practitioner Member	United States of America	Philadelphia	Pennsylvania
Future Farmers of America	Pre-college Partner	United States of America	Indianapolis	Indiana
Grinnell College	Non-ERC Institution Providing REU Students	United States of America	Grinnell	Iowa
Hamilton West High School	Pre-college Partner	United States of America	Philadelphia	Pennsylvania
Headwall Photonics, Inc.	Industrial/Practitioner Member	United States of America	Bolton	Massachusetts
Illinois Institute of Technology	Non-ERC Institution Providing REU Students	United States of America	Chicago	Illinois
Indiana State Department of Agriculture	Innovation Partner	United States of America	Indianapolis	Indiana
Ivy Tech Community College of Indiana	Community College	United States of America	Lawrenceburg	Indiana
Kensington High School	Pre-college Partner	United States of America	Philadelphia	Pennsylvania
Lankenau Environmental Science High School	Pre-college Partner	United States of America	Philadelphia	Pennsylvania

ERC Partner Name	ERC Partner Type	Country	City	State
Latino Farm Alliance	Innovation Partner	United States of America	Davis	California
Lower Merion High School	Pre-college Partner	United States of America	Philadelphia	Pennsylvania
Merced College	Non-ERC Institution Providing REU Students	United States of America	Merced	California
Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS)	Collaborating Institution	United States of America	Atlanta	Georgia
Morris Arboretum	Pre-college Partner	United States of America	Philadelphia	Pennsylvania
National Agriculture in the Classroom	Pre-college Partner	United States of America	Gainesville	Florida
North Carolina State University at Raleigh	Non-ERC Institution Providing REU Students	United States of America	Raleigh	North Carolina
Northeastern University	Non-ERC Institution Providing REU Students	United States of America	Boston	Massachusetts
Northwestern University	Non-ERC Institution Providing REU Students	United States of America	Evanston	Illinois
Pennsylvania Agriculture Cross-Sector Collaborative	Collaborating Institution	United States of America	Harrisburg	Pennsylvania
Pennsylvania Department of Agriculture	Innovation Partner	United States of America	Harrisburg	Pennsylvania
Pennsylvania State University-Main Campus	Non-ERC Institution Providing REU Students	United States of America	University Park	Pennsylvania
Princeton University	Non-ERC Institution Providing REU Students	United States of America	Princeton	New Jersey
Purdue University	Core Partner	United States of America	West Lafayette	Indiana
PureBiomass	Industrial/Practitioner Member	United States of America	New Hope	Minnesota

ERC Partner Name	ERC Partner Type	Country	City	State
RKE Tierra Consulting	Innovation Partner	United States of America	Tulare	California
Rodale Institute	Innovation Partner	United States of America	Kutztown	Pennsylvania
Santa Clara University	Non-ERC Institution Providing REU Students	United States of America	Santa Clara	California
Santa Fe College	Non-ERC Institution Providing REU Students	United States of America	Gainesville	Florida
Science Leadership Academy at Beeber	Pre-college Partner	United States of America	Philadelphia	Pennsylvania
SocioEnvironmental and Education Network (SEEN)	Innovation Partner	United States of America	Merced	California
SoilTech Wireless	Industrial/Practitioner Member	United States of America	Meridian	Idaho
Solutions from the Land	Innovation Partner	United States of America	Timonium	Maryland
Stevens Institute of Technology	Non-ERC Institution Providing REU Students	United States of America	Hoboken	New Jersey
Stichting IMEC Nederland - OnePlanet Research	Innovation Partner	Netherlands	Eindhoven	
Student Science Training Program	Pre-college Partner	United States of America	Gainesville	Florida
SunSouth, LLC	Industrial/Practitioner Member	United States of America	Dothan	Alabama
Swarthmore College	Non-ERC Institution Providing REU Students	United States of America	Swarthmore	Pennsylvania
Syngenta Crop Protection	Industrial/Practitioner Member	Switzerland	Basel	
Syracuse University	Non-ERC Institution Providing REU Students	United States of America	Syracuse	New York
The University of Texas at Dallas	Non-ERC Institution Providing REU Students	United States of America	Dallas	Texas

ERC Partner Name	ERC Partner Type	Country	City	State
The University of Texas at El Paso	Non-ERC Institution Providing REU Students	United States of America	El Paso	Texas
Treeswift (Trefos), Inc.	Industrial/Practitioner Member	United States of America	Philadelphia	Pennsylvania
Tuskegee University	Collaborating Institution	United States of America	Tuskegee	Alabama
UC Agriculture & Natural Resources	Innovation Partner	United States of America	Davis	California
University of California, Merced	Core Partner	United States of America	Merced	California
University of Florida	Core Partner	United States of America	Gainesville	Florida
University of Illinois at Urbana Champaign	Non-ERC Institution Providing REU Students	United States of America	Champaign	Illinois
University of Maryland Baltimore County	Non-ERC Institution Providing REU Students	United States of America	Baltimore	Maryland
University of Maryland Eastern Shore	Collaborating Institution	United States of America	Princess Anne	Maryland
University of Pennsylvania	Lead Institution	United States of America	Philadelphia	Pennsylvania
University of Pittsburgh	Non-ERC Institution Providing REU Students	United States of America	Pittsburgh	Pennsylvania
University of Puerto Rico at Humacao	Non-ERC Institution Providing REU Students	United States of America	Humacao	Puerto Rico
University of Tennessee Martin	Non-ERC Institution Providing REU Students	United States of America	Martin	Tennessee
University of Texas at Austin	Non-ERC Institution Providing REU Students	United States of America	Austin	Texas
US Golf Association	Innovation Partner	United States of America	Liberty Corner	New Jersey
Villanova University	Non-ERC Institution Providing REU Students	United States of America	Villanova	Pennsylvania

ERC Partner Name	ERC Partner Type	Country	City	State
W.B. Saul High School of Agriculture	Pre-college Partner	United States of America	Philadelphia	Pennsylvania
Wabash Heartland Innovation Network	Innovation Partner	United States of America	West Lafayette	Indiana
Walt Disney World	Collaborating Institution	United States of America	Lake Buena Vista	Florida

ERCWEB TABLE 5: Advisory Boards			
Name	**Professional Title**	**Department/Division**	**Organization/Firm**
Council of Deans			
Forrest Masters	Interim Dean, College of Engineering	Material Sciences	University of Florida
Dawn Bonnell	Senior Vice Provost of Research	Materials Sciences and Engineering	University of Pennsylvania
Rakesh Goel	Dean, School of Engineering	Environmental Engineering	University of California, Merced
Arvind Raman	John A. Edwardson Dean of the College of Engineering	Electrical and Computer Engineering	Purdue University
DCI & EWD Advisory Council			
Vilma Fuentes	Associate in Research	Learning Systems Institute	University of Florida
Edward Berger	Professor of Engineering Education and Mechanical Engineering	Mechanical Engineering Education Research Center	Purdue University
Daniel Miller-Uueda	STEAM Curriculum Specialist	School District of Philadelphia	School District of Philadelphia
Joshua Viers	Associate Dean for Research, School of Engineering	School of Engineering	University of California, Merced
Michael Johnson	Teacher and Executive Director, Philadelphia Robotics Coalition	Central High School and Philadelphia Robotics Coalition	Central High School and Philadelphia Robotics Coalition
Dania Matos	Vice Chancellor for Equity and Inclusion	Division of Equity & Inclusion	University of California, Berkeley
Beth Holloway	Assistant Dean for Diversity and Engagement	College of Engineering	Purdue University
Sharon Walker	Dean and Distinguished Professor; Executive Director	College of Engineering; ELATES	Drexel University
Camillo Taylor	Associate Dean of Diversity, Equity and Inclusion	Computer and Information Science	University of Pennsylvania
Sherine Obare	Dean of the Joint School of Nanoscience and Nanoengineering	Joint School of Nanoscience and Nanoengineering	University of North Carolina, Greensboro

Name	Professional Title	Department/Division	Organization/Firm
Curtis Taylor	Associate Dean for Student Affairs	College of Engineering	University of Florida
Gloria J. Kim	Professor and Associate Chair for Research	Department of Engineering Education, Herbert Wertheim College of Engineering	University of Florida
Entrepreneurship Mentors			
York Eggleston	CEO	N/A	Semantic Labs
Andy Ziolkowski	Managing Partner	N/A	Cultivian Ventures
Industrial (IPAB) and Agricultural (ASAB) Advisory Council			
Darren Raj	Owner	Business Development	Agribugs, LLC
Charlie Anderson	Chief Executive Officer	N/A	Augean Robotics, Inc (Burro)
Terry Scott	Chief Technology Officer	N/A	Augean Robotics, Inc (Burro)
Tony Green	Vice President	Technology Commercialization	Ben Franklin Technology Partners
Mark Moran	Director	Technology Innovation Center & Lead for Advanced Sensing	Deere and Co.
Wissam El-Ratal	Global Engineering Manager	Tractor VDV Engineering	Deere and Co.
Marcel Zevenbergen	Program Manager	Precision Agriculture & Food	IMEC - OnePlanet Research
Vincent Dupre	Manager	Precision Agriculture & Food	IMEC - OnePlanet Research
Russ Worsley	Integrated Solutions Manager	N/A	SunSouth, Inc.
Elizabeth Hunter	Chief Operating Officer	N/A	Treeswift (Trefos) Inc.
Cole Thompson	Director	Turfgrass and Environmental Research	U.S. Golf Association
Johnny Park	Chief Executive Officer	N/A	Wabash Heartland Innovation Network
Ryan McKibben	Government Analyst	Office of Energy	Florida Department of Agriculture and Consumer Services
Edward Barnes	Senior Director	Agricultural & Environmental Research	Cotton Incorporated
Jerry Davis	Producer	N/A	N/A

Name	Professional Title	Department/Division	Organization/Firm
Gene McAvoy	Associate Director for Stakeholder Relations	IFAS Southwest Florida Research and Education Center	University of Florida
Allison Randell	Director of Sustainability	N/A	American Peanut Council
Barzin Moradi	Branch Chief	Center for Analytical Chemistry	California Department of Food and Agriculture
Sam Stroebel	Data Analyst	N/A	Indiana State Department of Agriculture
Cheryl Cook	Deputy Secretary	Market Development	Pennsylvania Department of Agriculture
James Janni	Laureate	Applied Field Technologies	Corteva Agriscience
Kate Srinivasan	Client Engagement Manager	Strategic Initiatives Group and Investment Group	Ben Franklin Technology Partners
Mark Trabbold	Senior Vice President	Strategic Initiatives Group	Ben Franklin Technology Partners
Michael DeSa	Managing Director and Co-founder	N/A	AgSensor Solutions
Kenny Lee	Co-Founder - CEO	Aigen	Aigen
Richard Wurden	Co-Founder - CTO	Aigen	Aigen
Susana Diaz-Amaya	Head	Convergence	Bayer
Amanuel Ghebretinsae	Head	Global Production Science Discovery & Development	Bayer
Jordan Hesterman	Commercial Director	Precision Agriculture	FMC Corporation
Carla Niederhofer	Director of Engineering	N/A	Headwall Photonics
David Blair	VP	Product of Development	Headwall Photonics
John Howard	Chief Counsel	N/A	Pennsylvania Department of Agriculture
George Vozhdayev	Founder & CEO	N/A	Pure Biomass
Phoebe Gordon	Orchard Systems Advisor	Cooperative Extension	University of California

Name	Professional Title	Department/Division	Organization/Firm
Diganta Adhikari	Head	On-Farm IoT and ADP	Syngenta Group
Jeremy Groeteke	Head	Computational Agronomy	Syngenta Group
Anthony Fulford	Nutrient Management and Soil Quality Advisor	Cooperative Extension	University of California
James Ladless	State Program Leader	Emerging & Advanced Technology	Penn State Extension
Madhav Dhakal	Crop and Weed Specialist	N/A	Rodale Institute
Rigo Rios	National President /	N/A	Latino Farmers Alliance / TKE Tierra Consulting
Jose Luis Susa Rincon	CFO	N/A	SocioEnvironmental and Education Network (SEEN)
Chris Gaesser	Producer	N/A	Solutions from the Land
Sebastian Saa	Associate Director	Agricultural Research	Almond Board of California
Chris Parry	Research Scientist	N/A	Corteva Agriscience
Aaron Bianchi	Director	ML Solutions	Digital Divide Data
De Broughton	Crop Consultant, CCA	N/A	6 Gen Ag Services
Nathan Dorn	Director	Agriculture Business Development	Farm-ng
Zhenzhong Su	CEO & Co-Founder	N/A	FixPosition Ag
Keith Sandell	Director	N/A	MARVIL Inc
Clayton Hine	Business Development Manager	N/A	Nordic Semiconductor
Ray Gaesser	Producer	N/A	Solutions from the Land
Ehsan Soltan	Founder & CEO	N/A	Soiltech Wireless
Scientific Advisory Board			
Felix Fritschi	C. Alice Donaldson Professor	Division of Plant Sciences	University of Missouri
Daniel Schmoldt	National Program Leader (retired)	U.S. Dept. of Agriculture	National Institute of Food & Agriculture
Lynne Parker	Associate Vice Chancellor and Director of the AI Tennessee Initiative	N/A	University of Tennessee, Knoxville
Pramod Khargonekar	Professor / Vice Chancellor for Research	Electrical Engineering and Computer Science	University of California, Irvine

Name	Professional Title	Department/Division	Organization/Firm
Ana Claudia Arias	Professor	Electrical Engineering and Computer Sciences Department	University of California, Berkeley
Nancy Amato	Abel Bliss Professor and Interim Director	Siebel School of Computing and Data Science	University of Illinois at Urbana-Champaign
Student Leadership Council			
Harsh Pathak	Doctoral Student	Agricultural and Biological Engineering	Purdue University
Shobhita Kramadhati	Doctoral Student	Electrical and Systems Engineering	University of Pennsylvania
Samiul Basir	Doctoral Student	Agricultural and Biological Engineering	Purdue University
Jun Xu	Doctoral Student	Electrical and System Engineering	University of Pennsylvania
Kamila Dilmurat	Postdoctoral Fellow	Kamila Dilmurat	Purdue University
Sneha Jhu	Doctoral Student	Electrical and Computer Engineering	Purdue University
Anna Hampton	Doctoral Student	Electrical and Computer Engineering	University of Florida
Vernon Crasto	N/A	Electrical and Computer Engineering	University of Florida
Mehrad Mortazavi	N/A	Mechanical Engineering	University of California, Merced

3. EXECUTIVE SUMMARY

TOP THREE ACHIEVEMENTS

IoT4Ag was established on September 1, 2020. In Year 4, the Center has continued the excellent growth and execution of its programs and activities that deliver on the IoT4Ag strategic plan across the four foundational components: ***convergent research, engineering workforce development, diversity and culture of inclusion, and innovation ecosystem***. The Center's achievements are highlighted by examples:

Center-wide

- *Annual Meeting*
  - Accomplishment*:* IoT4Ag student-led "boot camp" (June 23-24) and Annual Retreat (June 24-26). Students, REUs, faculty, staff, and advisory board members gathered in-person at the University of California at Merced and the Bowles Farming Company.
  - Impact*:* Again, everyone was very happy and enthusiastic to be and work together! The Retreat was excellent for team building; research collaborations; and learning about IoT4Ag research, different agricultural needs and the agricultural environment in California, and each other's personal and professional interests and experiences.

Convergent Research

- *Sparse, Lightweight, Decentralized Metric-Semantic SLAM for Multi-Robot Navigation*
  - Accomplishment*:* Developed a real-time decentralized metric-semantic SLAM approach that uses a sparse and lightweight object-based representation to enable a heterogeneous robot team to autonomously explore 3D environments, including orchards, without relying on GPS. It maintains a hierarchical representation of the environment, from high-level sparse semantic maps (useful for inter- and intra-robot loop closure across flying and ground robots) to low-level voxel maps (useful for navigation).
  - Impact*:* This allows for autonomous robots to collaboratively build photorealistic maps of trees, e.g., maps that include both fruits and tree trunks for orchard yield estimation purposes, towards realizing a "digital twin of a farm". We created TreeScope, the first semantically segmented and ground-truth LiDAR dataset collected with robotic systems in agricultural environments to address the counting and mapping of trees in orchards and forestry. The dataset and code are made publicly available (https://treescope.org/) and the designs, reference architecture, and software for our drones are also open source https://github.com/KumarRobotics/kr_autonomous_flight.

- *Multi-resolution data fusion for detecting water stress*
  - Accomplishment*:* Integrated ground, UAV-based, and satellite data, allowing estimation of vegetation fractional cover with high spatial and temporal resolution. Showed that UAV-based multispectral data and satellite data can detect water stress in sorghum fields using both spectral indexes (e.g., NDVI) and machine-learning approaches.
  - Impact*:* This approach improves precision mapping for the application of irrigation while reducing labor, travel, and the overheads associated with high-frequency UAV acquisitions. This work is paving the way toward utilizing free, open-access satellite data has also lowered costs and democratized mapping, making the technology accessible to a broader group of end users.

- *Ag-Specific Communications*
  - Accomplishment*:* Developed and deployed Isoblue/Avena/NATS data pipeline for field scale testbed sensor networking. Integrated with OATSmobile spray platform enabling underground communications experiments for building underground communications channel models and backhaul to the cloud. Theory developed and extensive simulations for low-latency backhaul communications, simultaneous communications and wireless power transfer in near field channels, physical layer channel security, automated rural propagation modeling using site-specific terrain and obstructions, and integrated sensing and communications.
  - Impact*:* Isoblue/Avena/NATS framework allows sensor packages developed at any IoT4Ag lab to be plug-and-play deployable in any IoT4Ag testbed with internet connection (e.g., provided by LTE, 5G, WiFi, or LoRaWAN). OATSmobile platform, soon to be made autonomous, is available at Purdue/ACRE to provide backhaul communications and edge computing to support deployment tests of newly developed systems for integrated sensing and communications. Its backhaul connection allows completion of the entire Joint Op 1 data pipeline from sensors to decisions to actions. The open-source design of the OATSmobile will be ported as needed to support Joint Ops 2 and 3 in FL and CA.

Engineering Workforce Development

- *Launch of IoT4Ag E^3*
  - Accomplishment*:* IoT4Ag Empowering People Portfolio: Excite-Educate-Enable (IoT4Ag E^3) was rolled out with the addition of a new position, Director of Education and Inclusivity, charged with strategic integration and implementation of IoT4Ag's EWD and DCI programs. EXCITE - Tech Meets Ag serves pre-college and broader public audiences; EDUCATE for an Inclusive World trains and mentors community college through postdoctoral audiences; and ENABLE Professional Advancement engages a) farmers, end-users, and other professionals connected to agriculture, Ag education, and technology development, and b) professionals in education who influence Ag and STEM pathways of youth and students in higher ed.
  - Impact*:* IoT4Ag has a clearly communicated, cohesive vision and executable plan that integrates the EWD and DCI foundational components, which was identified as a priority by our Advisory Board members and most recent site visit team. IoT4Ag E^3 provides a Center-wide programmatic scaffold for outreach, education and inclusion synergies across the four foundational components.

- *EXCITE - Tech Meets Ag*
  - Accomplishment*:* IoT4Ag delivered 13 outreach events engaging over 900 attendees in Year 4, bringing the Center's cumulative numbers to 33 events and 2,912 attendees. IoT4Ag accelerated classroom reach of its lesson plans with 4 new educators in its Research Experiences for Teachers (RET) program.
  - Impact*:* IoT4Ag EXCITE is engaging with youth and public audiences in formal and informal learning environments about cutting edge technology creating "farms of the future" and about the opportunities that STEM and agriculture career paths allow for food, energy, and water security. Growing the number of partnering teachers magnifies the number of youth affected and paves the way for longer term impact on educational systems.

- *EDUCATE for an Inclusive World and ENABLE Professional Advancement*

- Accomplishment: IoT4Ag EDUCATE trained and mentored 24 postdoctoral fellows, 91 graduate students (72 at the PhD-level), and 73 undergraduates (plus an additional 47 visiting community college and 4-year college students through the Research Experiences for Undergraduates (REU) program) since the Center launched in 2020. ENABLE activities spanned the range of partner-building with small organizations like Latino Farmers Alliance, to Extension-partnered technical workshops, to exhibit booths at large venues like the World Ag Expo 2024 (100,000+ attendees).
- Impact: IoT4Ag touches and transforms students, postdocs, practitioners and professionals in a diversity of settings and institutions around Center research and innovation, and Agriculture and STEM careers.

Diversity & Culture of Inclusion

- *EXCITE - Tech Meets Ag serves Diverse Audiences*
  - Accomplishment: Among many other EXCITE activities, IoT4Ag engaged 580 6th-12th graders at a) a summer camp for ACLAMO, a Latino-focused Community-Based Organization, b) Junior MANRRS, the youth component of the National Society for Minorities in Agriculture, Natural Resources and Related Sciences, and c) a STEM middle school camp at Tuskegee University.
  - Impact: IoT4Ag delivers lesson plans and curricular activities at sites and events that reach underserved and/or historically underrepresented audiences in agricultural, Ag-Tech, and STEM disciplines.

- *EDUCATE for an Inclusive World increases accessibility of advanced degrees in STEM and Ag-Tech*
  - Accomplishment: In September 2023, IoT4Ag ran the 3rd Pathways to PhD Program (PPP) intensive workshop for 42 mentees interested in applying to graduate school; following an overview of the STEM graduate school application and funding processes, mentees were matched to 25 PhD and postdoctoral mentors who provided personalized mentoring and feedback on the mentees' personal and research statements during the all-day, open-to-all workshop and over the course of the 6 weeks that followed.
  - Impact: Since PPP's inception in 2021 and including 2024's ongoing program, nearly 200 mentees have gained a better understanding of the STEM PhD applications process and have been able to receive personalized feedback on their application materials. 12 graduate students and postdocs have served as mentors for 2 or more years (total of 80 mentor slots filled over the 4 years), which confirms that PPP serves as a valued opportunity to develop and practice mentoring skills.

- *ENABLE Professional Advancement for and partnering with MSI and HBCU faculty*
  - Accomplishment: IoT4Ag's MSI-HBCU Partners Network Program welcomed its first two faculty; these professors, from University of Maryland Eastern Shore and Hampton University, each spent ~4 weeks in residency at IoT4Ag during Summer 2024.
  - Impact: This program catalyzes strong, sustainable partnerships between IoT4Ag institutions and MSI HBCU institutions through collaborative research and education.

Innovation Ecosystem

- *Adoption Readiness Level*
  - Accomplishment: Building on the widely used technology readiness levels (TRLs), the center has adopted another assessment called adoption readiness levels (ARLs). ARL quantifies how widespread is the user base of a given technology.

- Impact: In addition to technically maturing technologies, there is overt emphasis on getting the technologies into the hands of other users. Our TRL+ARL approach allows us to monitor both "tech push" and "market pull."

- *Invention*
  - Accomplishment: During Year 4, IoT4Ag added 7 new invention disclosures and 13 patent application filings (for lifetime total of 15 disclosures, spanning all four institutions, and 21 patent applications). The center also has a significant portfolio of software assets.
  - Impact: IoT4Ag research is creating significant intellectual property at a rate of $1.3M/disclosure.

- *Commercialization/Entrepreneurship*
  - Accomplishment: IoT4Ag has fueled a vibrant startup culture across all institutions, including Perfect Pitch competition engagement, two NSF I-Corps teams, Penn Y-prize, Wharton Business School case analysis, and recent discussion with the IPAB about the formation of an industry-funded innovation seed fund.
  - Impact: Capitalizing on centerwide education and encouragement over the first few years, IoT4Ag is actively commercializing multiple center intellectual properties.

RESPONSE TO SWOT

Here, we paraphrase and present high-level actions in response to the NSF Year 4 Site Visit Team (SVT) report on center Strengths, and in combination on Weaknesses, Opportunities, and Threats, given their common themes. Details of the SWOT analysis and our response are presented in follow up sections.

Strengths:

- The Center has an impressive **vision** that can transform the agricultural landscape through innovation in digital agriculture and interdisciplinary research, translational plans, and interdisciplinary training. There is incredible potential of the Center to highly transform food, energy, and water management. Thanks for the feedback!

Weaknesses, Opportunities, and Threats:

- The peer-reviewed publication count seems low given the number of participants and the size of the award and when benchmarked against other ERC's.

→ We appreciate the importance of publications to the dissemination of IoT4Ag research and as a measure of Center productivity. The center publication record grew significantly in YR4, as seen in the data below. As center research has matured, we expect this growth trajectory will continue in YRs 5-10.

	YR1	YR2	YR3	YR4
Peer-reviewed Technical Journals	1	5	3	23
Peer-reviewed Conf. Proceedings	4	2	11	15

To provide some context to the publication numbers for the center, we note that (1) the nature of some of the Center's agricultural research projects involve multi-year field-based measurements and analysis that take time to conduct, analyze, and publish, (2) IoT4Ag launched during the pandemic and thus the Center publication rate in the first couple of years may be slower than historical ERC averages. We enjoy working with our students and supporting them as they work to complete and publish their/Center research.

- The large amount and diversity of data being collected and curated could be shared with other communities outside the Center (e.g., those working in AI/ML). Sharing the data could support the development of new models, algorithms.

→ IoT4Ag is collecting and curating data and is beginning to share it with communities outside the Center. In Year 4, IoT4Ag shared Treescope, LiDAR and ground-truth data set for semantic segmentation and diameter estimation to address the counting and mapping of trees in orchards and forests, code is also shared via Github (https://treescope.org/). The Center has begun discussions with potential industry partners to host IoT4Ag data sets.

- The Center Leaderships should provide a clearer presentation and strategy that balances R&D thrusts with product deployment.

→ We have articulated a vision for a balance between deployment in the Joint Ops and core R&D for Years 6-10 in Section 4D. Convergent Research. We will place greater emphasis on the Joint Ops in coming years toward achieving the 10-year Center vision.

- The Center creates a significant opportunity to get a wider group of students more aware of food production and rural issues. Many students are interested in sustainability and energy, which has a strong connection to agriculture. Reaching out to students/groups interested in energy/sustainability to connect to agriculture and IoT4Ag could be very fruitful. Thanks for the feedback.

- The large and complicated administrative infrastructure, and the way it is structured seems to take a lot of time and effort from researchers and leadership and hinder a smooth-running ERC. Communication strategies should be evaluated to understand information flow".

→ We evaluated the frequency and timing of administrative work requests to lower their burden and frequency. One change we made in YR4 was to organize the meetings for consistent timing and to reduce the # of meeting days. We have structured these meetings as follows: 1st Friday for monthly seminars, 2nd Friday for thrust and testbed meetings, and 3rd Friday for Center-side meetings. We will keep the 4th Friday clear to allow for a day off from IoT4Ag meetings.

We have strengthened the use of Slack as the IoT4Ag communication tool, encouraging faculty and students to communicate outside of email across the Center. We utilize and have streamlined the channels for specific groups, including the student leadership groups. Originally, the SLC (now SPLC) established an independent Slack group, and therefore this Slack membership/ activity was not captured in the IoT4Ag usage and statistics. At the request of the SPLC, we have brought the student Slack channels within IoT4Ag to facilitate student effective and efficient communication and to better capture that data for reporting purposes.

We continue to use our weekly Monday event notice email, sent via MailChimp, to inform all members of upcoming meetings and events as well as job and internship opportunities, IoT4Ag social media links, ITEX application procedures, and other useful links and information.

- We suggest that the ERC faculty members provide sufficient support to students for publishing research. The SVT understands that cross-disciplinary work can sometimes be challenging to publish, as it can often not be deep enough in the fields it is touching on. Prioritizing publications will help showcase the advancements and goals of the Center.

→ We appreciate the importance of publications to the dissemination of IoT4Ag research and as a measure of Center productivity. We are happy to support our students in publishing their research.

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4A. VISION & IMPACT

VISION

By 2050, the US population is estimated to grow to 400 million and the world population to 9.7 billion. Current agricultural practices account for 70% of global water use, energy use is one of the largest costs on a farm, and inefficient use of agrochemicals is altering Earth's ecosystems. With finite arable land, water, and energy resources and with the negative impacts of climate change, ensuring food, energy, and water security will require new technologies to improve the efficiency of food production, create sustainable approaches to supply energy, and prevent water scarcity.

The IoT4Ag vision is to ***ensure food, energy, and water security by advancing technology to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment.***

Monitoring of agricultural crops is still accomplished primarily through the expensive, labor-intensive, and time-consuming process of crop scouting, by manual sampling and documenting the state of the field. Precision agriculture involves the use of technology to acquire and analyze data from the field. However current technologies such as sensors are inadequate to spatially, temporally, and compositionally monitor the state of the field, data is coarse-grained and siloed in equipment, communications infrastructure is limited or non-existent on the farm, and interventions are reactive and over-provisioned, increasing economic cost and environmental impact. While the concept of precision agriculture has existed for 30 years, the *exponential growth in information technology and data science and the reduction in their cost is setting the stage for the next revolution in agricultural practices.*

The mission of IoT4Ag is to ***create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.***

To do so, IoT4Ag is creating novel, integrated systems that capture the microclimate and spatially, temporally, and compositionally map heterogeneous stresses for early detection and intervention to ensure sustainable agricultural crop production with reduced environmental impact and improved yield. The Center is working to realize IoT technologies to optimize practices for every plant; from sensors, robotics, and energy and communication devices to AI-driven digital twins of row and tree crops and human-centered Ag-decision interfaces for agricultural management. Diverse participant groups have been recruited and have been/are being trained through IoT4Ag educational and inclusion programs to have strong agricultural, physical, informational, and social science and engineering knowledge. The Center is building a workforce able to discover, innovate, translate, and practice precision agriculture solutions. IoT4Ag has established and continues to expand an innovation ecosystem and network with academic, industry, investment, and government partners to collaboratively position its technologies, systems, and people needed to build the future of precision agriculture and meet the societal challenge of food, energy, and water security.

CENTER INTEGRATION

The IoT4Ag mission integrates the Center across the four ERC foundational components of convergent research, engineering workforce development, diversity & culture of inclusion, and innovation ecosystem. The Center's approach and interdependence of IoT4Ag's programs is exemplified by the following narratives:

IoT4Ag Boot Camp and Annual Retreat: Each summer, IoT4Ag holds an annual, student-led Boot Camp and an Annual Retreat, bringing together IoT4Ag postdocs and students, REUs, faculty, staff, and advisory board members from all ERC foundational components. In Year 1, these meetings were held virtually due to the COVID-19 pandemic. But in Year 2, these events were held in person on the main campus of and at the Beck Agricultural Center of Purdue University. In Year 3, IoT4Ag traveled to the University of Florida and also its neighboring North Florida Research and Extension Center at Live Oak, FL. And, in Year 4, IoT4Ag came together at the University of Merced and the Bowles Farming Company. These meetings integrate programming from ***all four ERC foundational components***. They are always excellent events in building Center ***climate*** and for IoT4Ag colleagues to work collaboratively in pursuit of Center goals and to learn from and about each other and our regional agricultural environments, production systems, and needs. Our ASU evaluation team participates in the Retreat and carries out post-meeting surveys. For the Year 4 Annual Retreat, the evaluation team reported "The annual meeting was perceived to be generally well organized and largely met participants' expectations. It was widely considered successful, providing significant opportunities for engagement and networking. The sessions typically enhanced participants' understanding of the Center."



Figure 4A.1 Photos of the Year 4 IoT4Ag Student Boot Camp at UC Merced. Students travel to and learn about water and environmental management in California at the Dos Rios State Park.

Again, in Year 4, the Boot Camp was organized by and for the students, with the support of IoT4Ag faculty and staff. This year, the Camp began with a student & postdoctoral fellow BBQ dinner (***climate***), as participants arrived in Merced, CA, and kicked off an early morning with a Breakfast Tailgate (***climate***). Students then traveled to Dos Rios State Park (**Fig. 4A.1**), California's largest public-private floodplain restoration project, where students learned about the impact of climate change and the work to mitigate flood and drought risks, replenish groundwater essential to agriculture (particularly important in water scarce CA), and ensure wildlife safety (***research*** and ***engineering workforce development***). Camp again included a student-industry/end-user mixer (***innovation ecosystem***), this time at lunch. The afternoon continued with a panel discussion on inclusive and climate-smart innovation in agriculture, with panelists from the Valley Institute for Sustainability, Technology, & Agriculture (UC Merced) and a Venture Capitalist (***diversity & culture of inclusion***, ***innovation ecosystem***). The group then broke out into meetings of the 2024 cohort of the 15 REU students representing all four IoT4Ag campuses and of IoT4Ag graduate students and postdoctoral fellows. The REU students

participated in one-on-one interactive icebreakers with every other REU student and then a "scavenger hunt" based on Boot Camp activities (***climate***, ***engineering workforce development***). IoT4Ag's Student and Postdoc Leadership Council (SPLC) led graduate students and postdocs in a Triannual Check-In, discussing the work and governance structure of the SPLC and collecting feedback and suggestions to improve the Center and student experiences (***all four foundational components***). While the students had their meetings, the faculty arrived for a meeting on renewal planning and an update on Center assessment from our ASU evaluation team (***all four foundational components***).



Figure 4A.2. Photos of the Year 4 IoT4Ag Annual Meeting at UC Merced, (a) the poster session and (b,c) the opening keynote lecture, (d-h) visit to Bowles Farm, (i,j) Joint Ops panels on pests and water, (k) the IoT4Ag perfect pitch "competition", and (l) IoT4Ag students working together.

The Annual Retreat then kicked off (**Fig. 4A.2a-c**) with an evening reception and poster session (***climate***, ***research***) followed by a working dinner and keynote lecture by Shely Aronov, CEO and Co-founder of InnerPlant. The speaker was selected based on recommendations by IoT4Ag IPAB members. Aronov shared her experiences in founding a company, raising venture capital, negotiating deals, and product deployment, and described what is needed to succeed in an "Ag-Tech business … beyond good technology" (***innovation ecosystem***).

The following day began with another early tailgate breakfast and takeoff for Bowles Farming Company (in an effort to beat the 100+ ºF day's high temperatures). Bowles Farming Company is a family farm which grows a wide range of crops and has a focus on sustainable practices. We learned from their President/CEO Michael Cannon about the company's farm management practices, including their use of precision irrigation systems and 5-year crop rotation planning, and their commitment and support of employees, equipment ownership and outsourcing of services, and attention and responsiveness to

California's regulatory environment (**Fig. 4A.2d**). We then toured the farm, saw mechanized carrot harvesting, and learned about the complexities of almond cultivation (**Fig. 4A.2e-h**) (***all four foundational components***).

We returned from the farm to have lunch and a second poster session, as the poster sessions are always an IoT4Ag team favorite. We then held two panel discussions on the agricultural opportunities and challenges being pursued by our Joint Ops (**Fig. 4A.2i,j**) (***research***, ***innovation ecosystem***). The first, Joint Op 3: Integrated Systems to Mitigate Disease and Pests panel was moderated by James Krogmeier (Purdue/IoT4Ag) and featured panelists Gene McEvoy (ASAB – Associate Director for Stakeholder Relations, University of Florida IFAS Southwest Florida Research and Education Center), Dan Schmoldt (SAB – National Program Leader, USDA retired), and Andrea Joyce (UC Merced – Associate Professor, Entomologist). The second Joint Op 2: Integrated Systems to Optimize Water Use in Tree Crops panel was moderated by Erin Hestir (UC Merced/IoT4Ag) with panelists Ryan McKibben (ASAB – Florida Dept. of Agriculture & Consumer Services), Carolyn Cook (California Dept. of Food and Agriculture), Ric Ortega (Grassland Water District); Eduardo Currea (Rivulis); and Kevin Assemi (Elevated Ag). We then held two concurrent breakout sessions. The first breakout was a panel on Student Career Development, moderated by Kristin Field (IoT4Ag Director of Education and Inclusivity) with panelists Sarah Kurtz (UC Merced & National Academy of Engineering), Jeremy Groeteke (IPAB – Syngenta), Jordan Hesterman (IPAB – FMC), and Barzin Moradi (ASAB – CA Dept. of Agriculture) (***engineering workforce developmen***t, ***diversity & culture of inclusion***, ***innovation ecosystem***). The second breakout session was on Center Sustainability in which Pramod Khargonekar (SAB – UC Irvine) gave a presentation and then led the faculty and staff through a discussion as IoT4Ag plans for sustainability (***all four foundational components***). Everyone came back together for a panel on Stakeholder Engagement moderated by Katie Stofer (UF/IoT4Ag) with panelists Maria Ridoutt-Orozco (Community Alliance with Family Farmers), Jim Ladlee (ASAB – Penn State Ext), and Rigo Rios (ASAB - Latino Farmers Alliance / TKE Tierra Consulting) (***all four foundational components***). We had one final set of breakout sessions, one on Community College Engagement with Sue Ann Bidstrup-Allen (Penn/IoT4Ag) and Karen Aceves (Ag Tech Workforce Initiative) (***engineering workforce development***, ***diversity & culture of inclusion***); and the second on Entrepreneurship start-ups, moderated by Steven Weiner (IoT4Ag ILO) with our innovation mentors as panelists, Andy Ziolkowski (Cultivian Ventures) and York Eggleston (Semantic Labs) (***innovation ecosystem***). The day finished with a presentation by our ASU evaluation team and four bold students who presented and competed in the Perfect Pitch (**Fig. 4A.2k**) (***all four foundational components***).

The next morning the team came back together. We announced our poster award winners and our Perfect Pitch winner, Marcos Zuzuarregui (UC Merced). Marcos just represented IoT4Ag at the NSF ERC Biennial Meeting Perfect Pitch Competition. Our ASU Evaluation Team led the group through an Evaluation Survey of the Retreat. The Annual Retreat came to a close, once again with great enthusiasm for the experiences we shared (**Fig. 4A.2l**), the knowledge we gained, and the relationships and collaborations we built (***all four foundational components***).

IoT4Ag Integrative Programs: Bridging People, Places, and the (Internet of) Things: IoT4Ag four core partner universities are located in the Northeast (Penn), South (UF), West (Merced), and Upper Midwest (Purdue) United States. Our regions represent different climates, cropping systems, and regulatory and socioeconomic environments. Our students (from K-12 to professionals), staff, faculty, and stakeholders embody a diversity of identities and of interests. To

broaden participation; exchange our interests, experiences, and our knowledge; and to maximize the impact, inclusivity, and adoption of our technologies and systems, IoT4Ag has established programs that are integrated across the ***four ERC foundational components***. These programs are delivering on and are accountable to the Center's strategic plan, mission, and vision and their contributions to Center goals are illustrated in **Figure 4A.3**, a new graphic designed to represent the structure and improve the communication of IoT4Ag integrated programming, playing on and in analogy to the interdependent structure and function of and communication between plants. The cross-cutting programs highlighted in this figure are detailed in reporting of our foundational components and are also found in our logic models, annual cadence roadmaps, and 10-year milestone charts, for each of our foundational components.

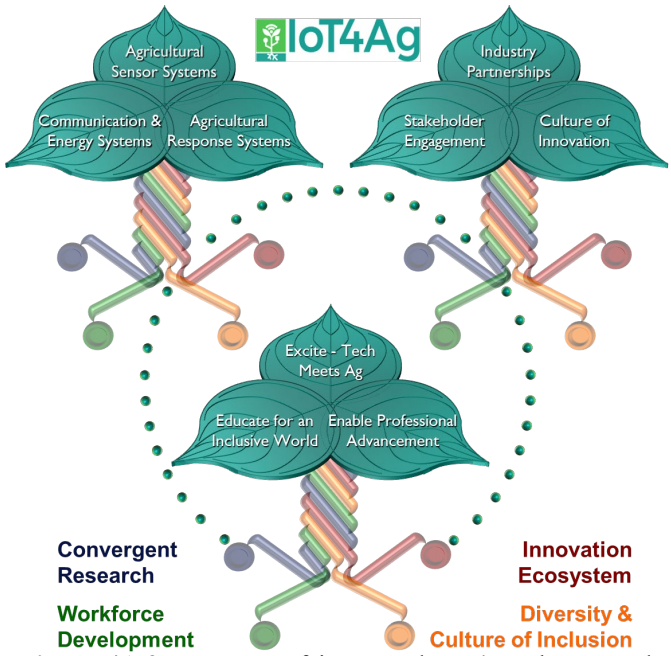


Figure 4A.3 Summary of integrated IoT4Ag thrusts and programmatic axes and their relationship to the four NSF Gen-4 ERC Foundational Components.

Our goals and the integrative nature of our programs are responsive to the diversity of people, places, and (Internet of) Things. IoT4Ag aims to create, sustain, and promote a diverse community of participants through programs appropriate for students and teachers at different stages, from K-12 students and teachers, Community College students, and undergraduate and graduate students and postdoctoral fellows; and for Ag/Tech professionals and stakeholders with different careers, whether members of our IPAB or ASAB or more broadly participating in the community. Programs are designed so participants grow and share their expertise and personal experiences by learning from, contributing to, and guiding IoT4Ag programs across all four foundational components; and with the aim of helping to build the future technical workforce developing and the end user community that adopts and puts to practice in farming IoT4Ag next-generation precision Ag technologies.

To highlight a few examples:

- **Engineering Workforce Development - Diversity & Culture of Inclusion**: In Year 4, IoT4Ag established a new Director of Education and Inclusivity position and hired Dr. Kristin Field. In partnership with our advisory boards and in response to feedback from last year's NSF Site Visit, we undertook an evaluation of the structure, function, and integration of our EWD and DCI programs and activities to ensure intentionality and to deliver on our goals. We introduced the IoT4Ag Empowering People Portfolio, we call for short, **IoT4Ag E^3**: EXCITE - Tech Meets Ag, EDUCATE for an Inclusive World, and ENABLE Professional Advancement (**Fig. 4A.3, bottom**) and established a set of guiding principles to ensure the selection, creation, execution, and sustainability of our portfolio of programs and activities (see **Sections 4E: Engineering Workforce Development** and **4F: Diversity & Culture of Inclusion**).

- **Innovation Ecosystem - Engineering Workforce Development - Diversity & Culture of Inclusion**: IoT4Ag established the non-dues-paying **Agricultural Systems Advisory Board (ASAB)** to ensure the inclusion and stakeholder engagement of diverse perspectives in our research, education, and innovation activities. We intentionally include representatives of small farms, farm workers, rural regions, indigenous communities, and other underserved communities in agriculture and representatives advancing education and the environment. In Year 4, IoT4Ag added new ASAB members representing the Latino Farmers Alliance, Solutions from the Land, and the SocioEnvironmental and Education Network. Early in Year 5, we welcomed David Jeng to our ASAB. A member of the National IP Council of The Gambia, management consultant, and expert innovation trainer, David brings deep commitment to empowering agricultural actors in the developing world.
- **Research - Innovation Ecosystem - Diversity & Culture of Inclusion** - IoT4Ag has systematically fueled a vibrant innovation pipeline, translating research discoveries to stakeholder needs. In the first few years, we focused on center wide education on innovation/entrepreneurship, offering training sessions and the engagement of two external entrepreneurial mentors. By establishing an innovation culture and helping our team learn the processes, IoT4Ag has generated 15 invention disclosures, spanning all four institutions, 21 patent applications, and a significant portfolio of open-source software assets. Faculty and students are now actively participating in multiple startup endeavors ranging from Perfect Pitch, Penn Y-prize, Wharton Business School case analysis, Innovators Ignite 2024: A Yale & Penn Showcase, and two NSF I-Corps teams.

IMPACT

IoT4Ag is impacting the Engineering and Agricultural Communities, the Scientific Enterprise, and Society through the programming of the four ERC foundational components, convergent research, workforce development, diversity & culture of inclusion, and innovation ecosystem, best articulated through our mission ***to create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.***

IoT4Ag is driven by the agricultural-specific use cases of IoT technologies. e.g., the scale, the outdoor environment, and the socioeconomics. It is pushing the fundamental scientific understanding and bringing together the tools of our disciplines, i.e., the fields of agronomy, agricultural engineering, agricultural economics, environmental science, and of chemistry and chemical engineering, computer science, and electrical, materials, mechanical, and systems engineering. It is propelling us, in partnership with our innovation ecosystem, to create "IoT4Ag breakthrough technologies" in:

- Multi-mode, low-cost, distributable, environmental and soil sensor technologies
- Autonomous aerial and ground-based robots
- Energy storage and delivery technologies for field-scale operation
- Ag-specific edge and backhaul communications
- AI-driven digital twins of row and tree crops
- Human-centered decision-Ag interface for agricultural management

The fundamental knowledge and enabling technologies are intimately connected. For example, IoT4Ag is working to probe the theoretical limits of electromagnetics, important to understanding

signals in the soil, canopy occlusion, and signal interference; to create a suite of Ag-specific communication technologies that connect sensors located in remote and obstructed agricultural environments to the cloud. The Center is advancing materials properties, e.g., from host-guest chemistry to low-cost processable, biodegradable, and biocompatible materials; and manufacturing approaches to realize sensors that sense variables of interest and energy devices that operate in soil, both of which must meet the Ag-specific constraints of device cost and number, and the scale of device distribution and measurement, using approaches/infrastructure consistent with farming practices. IoT4Ag is developing AI-driven digital twins of row and tree crops and machine learning algorithms to deliver robust predictive models that effectively capture site-to-site variability and decision science to synthesize human-centered interfaces for decision-Ag interventions that are interpretable, risk-based, and economically feasible. Coming full circle, IoT4Ag 'sense-communication-response' technologies are impacting agronomy, addressing fundamental scientific questions such as understanding how abiotic and biotic variables affect crop yield and resilience.

The convergence of knowledge and technologies from these principal disciplines is allowing IoT4Ag to create integrated systems that capture the microclimate and spatially, temporally, and compositionally map heterogeneous stresses for precision farming of tree and row crops, i.e., to realize IoT technologies for early detection and intervention to sustainably better outcomes in agricultural crop production. More broadly, the scientific and engineering advances of the Center will impact the development of emerging hardware and software for IoT technologies pervading society in household products, health care, transportation, manufacturing, and energy and environmental management. IoT4Ag Joint Ops are bringing together our technologies in our testbeds to create integrated systems for precision farming of row and tree crops and are tackling key challenges to farm management - - to optimize nitrogen use in row crops and water use in tree crops and to mitigating the impact of disease and pests, important to realizing sustainable agricultural practices, meeting increasingly challenging regulations, and managing the cost to produce and the security of food. As evidence of impact, our faculty/students have generated 15 invention disclosures, spanning all four institutions, 21 patent applications, and a portfolio of open-source software assets. Capitalizing on center wide focus on innovation/entrepreneurship, IoT4Ag is actively commercializing multiple center technologies through NSF I-Corps and other business plan competitions.

IoT4Ag integrative programs and engagement with different communities across the U.S. and abroad, includes people with a diversity of interests and identities, from students (from K-12 to professionals), staff, faculty, and stakeholders. Our stakeholders comprise academic, industry, investment, and government partners and the end-user farming community, with representation from small farms, farm workers, rural regions, indigenous communities, and other underserved communities in agriculture. The Center and its programs bring people together to grow and share their expertise and personal experiences by learning from, contributing to, and guiding IoT4Ag programs. These programs are establishing a well-educated and diverse workforce knowledgeable about agricultural, physical, informational, and social science and engineering, and that are able to discover, innovate, translate, adopt, and practice IoT4Ag next-generation precision Ag technologies. IoT4Ag is bridging the people, places, and (Internet of) Things to build a diverse workforce, exciting future agricultural professionals, and farmers through the introduction of technology, and conversely scientists and engineers through the application domain of agriculture and the opportunity to address the societal grand challenge of food, energy, and water security.

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4B. STRATEGIC PLAN

AGRICULTURAL PRACTICES TODAY

Today, monitoring of agricultural crops is still accomplished primarily through the expensive, labor-intensive, and time-consuming process of crop scouting, by manual sampling and documenting the state of the field. Current precision agriculture, such as sensors are inadequate to spatially, temporally, and compositionally monitor the state of the field, data is coarse-grained and siloed in equipment, communication infrastructure is limited or non-existent on the farm, and interventions are reactive and over-provisioned, increasing economic cost and environmental impact.

THE IOT4AG VISION AND MISSION

The IoT4Ag vision is to ensure food, energy, and water security by advancing technology ***to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment.***

To deliver on our vision, the IoT4Ag mission is to create and translate ***to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.***

IOT4AG STRATEGIES

Goals: To achieve the IoT4Ag vision and mission and transform agricultural practices in sustainably increasing the production of high-quality crops in the US and across the globe, IoT4Ag aims to build the farm of the future (**Fig. 4B.1**) and a diverse workforce able to discover, innovate, translate, and practice precision agriculture solutions.

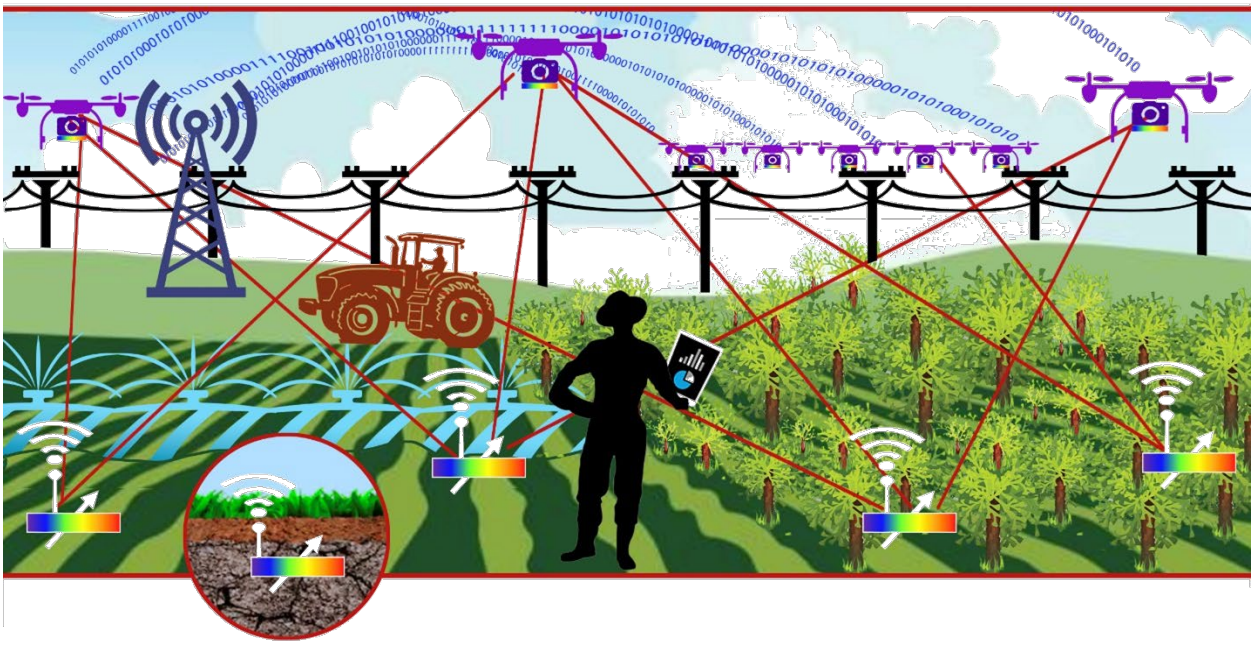


Figure 4B.1 Schematic of the IoT4Ag "Farm of the Future" transforming agriculture today.

Activities: Through IoT4Ag ***convergent research***, and with the guidance of and in partnership with our ***innovation ecosystem***, the Center is working to create cost-effective, integrated systems for row and tree crops that provide early detection of plant stress and environmental conditions in the field and that allow more efficient use of energy, water, and agrochemicals. The integrated systems (**Fig. 4B.1**) are composed of IoT sensors and a robotic fleet, that are powered by appropriate energy devices and work with existing farm machinery, to map plant and environmental targets in unstructured fields at scale; agricultural-specific edge and backhaul communications technologies to transmit signals from the field to the cloud; and AI-driven digital twins of row and tree crops, incorporating plant physiology, soil, weather, management practices, and socioeconomics; that yield responses shared via human-centered Ag-decision interfaces for agricultural management so farmers can take action.

The Center's ***engineering workforce development*** and ***diversity & culture of inclusion*** foundational components are recruiting and engaging diverse participant groups to be ***excited***, ***educated***, and ***enabled*** through the **IoT4Ag Empowering People Portfolio: Excite-Educate-Enable** of educational and inclusion programs, which we call for short **IoT4Ag E^3**. IoT4Ag has established and continues to expand an ***innovation ecosystem*** and network with academic, industry, investment, and government partners to collaboratively position its technologies, systems, and people needed to build the future of precision agriculture and meet the societal challenge of food, energy, and water security.

IoT4Ag activities and programs are integrated across the ***four ERC foundational components***. These activities and programs are delivering on and are accountable to the Center's vision, mission, and strategic plan and their contributions to Center goals are illustrated in **Figure 4B.2**, a new graphic designed to represent the structure and improve the communication of IoT4Ag integrated programming, playing on and in analogy to the interdependent structure and function of and communication between plants. The cross-cutting thrusts and programmatic axes highlighted in this figure are used to describe our strategic plan and are detailed in reporting of our foundational components in **Sections 4D-G**.

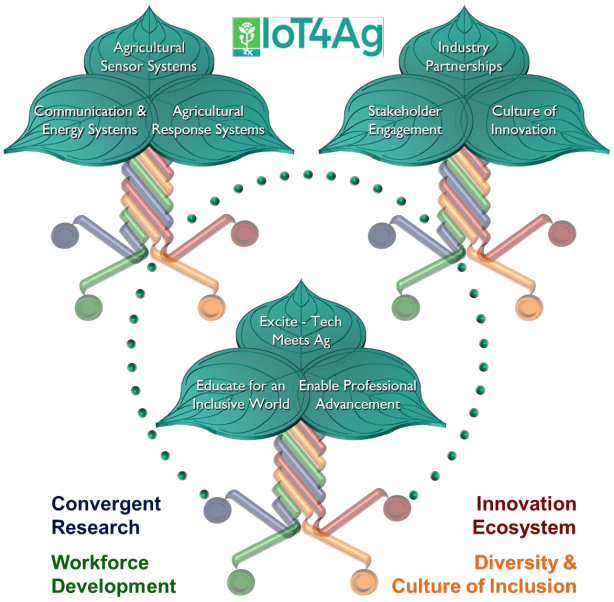


Figure 4B.2 Summary of integrated IoT4Ag thrusts and programmatic axes and their relationship to the four NSF Gen-4 ERC Foundational Components.

Structure and Processes – Progress Towards Goals & Milestones – Steps Taken in Response to the NSF Site Visit Team SWOT: The structure and processes of IoT4Ag's strategic plan allow for the Center to be dynamic and responsive in serving its vision and mission now and in the future.

Convergent Research: IoT4Ag **convergent research** is structured into three Thrusts. Thrust 1: Agricultural Sensor Systems; Thrust 2: Communication and Energy Systems; and Thrust 3: Agricultural Response Systems (**Fig. 4B.2, top left**). The projects in the Thrusts work collaboratively to deliver on the Center's goals of creating integrated sensor-communication-response systems and demonstrating solutions in the testbeds: Integrated Systems of Row and Tree

Crops. In Year 2, the Center established Joint Ops, a deliberate structure and planning process that brings individual IoT4Ag technologies together into systems in our row and tree crop testbeds to address significant challenges to enable environmentally sustainable and resilient agricultural production for years to come. We initially defined two Joint Ops: (1) Integrated systems to optimize N application in row crops and (2) Integrated systems to optimize water use in tree crops. In Year 3, guided by input from our advisory boards, we launched the third Joint Op, (3) Integrated systems to mitigate disease and pests. We now solicit and evaluate ideas for new Joint Ops as part of our annual basis (see details below).

As detailed in **Section 4.D**, convergent research has an annual roadmap for project definition, design, development, deployment, evaluation, and selection, which provides for guidance from our advisory boards and for projects to be chosen, merged, or sunset to meet IoT4Ag strategic goals. In Year 4, 23 multi-institutional, multi-disciplinary, multi-thrust research projects vertically integrating the ERC 3-planes of fundamental knowledge, enabling technologies, and integrated systems across three horizontally integrated research thrusts were carried out. These research projects are aligned with the IoT4Ag mission and strategic plan and are positioned to deliver on the IoT4Ag vision. The IoT4Ag 10-year milestone chart is constructed to allow for horizon scanning and to set up the Center to achieve the outputs and outcomes in its research Logic Model. In response to the Year 2 SVT report, we updated the IoT4Ag 10-year milestone chart to depict current Center projects, their technology readiness levels (TRLs), and their connectivity to show how they are contributing to IoT4Ag "breakthrough technologies". In Year 4, we added an adoption readiness level (ARL) evaluation (**Fig. 4B.3**). Project TRLs and ARLs, shown in **Figure 4B.3**, provide a mechanism for understanding the progress of projects towards testbed deployment and toward technology translation and adoption. To measure the progress of IoT4Ag research toward center-level goals, each research Thrust creates a set of annual research milestones. The milestones are detailed in **Section 4D. Convergent Research**.

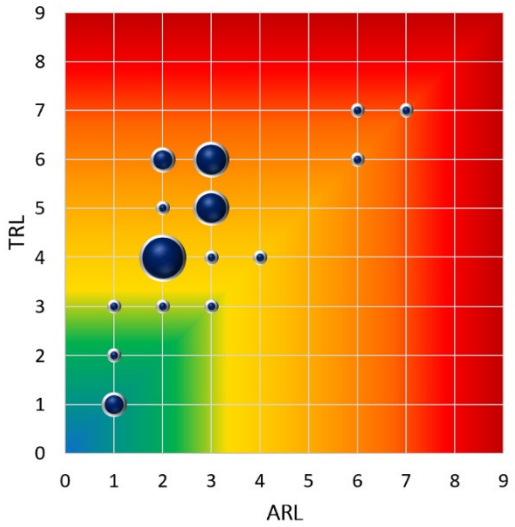


Figure 4B.3. Plot of technology readiness level (TRL) and adoption readiness level (ARL) for all active center projects. The size of the bubble represents the number of projects at that TRL/ARL (ranging here from 1 to 4).

In Year 4, research milestones were achieved across all thrusts. In Thrust 1, this included field testing of soil and leaf sensors, UAV-based mapping and yield estimation of orchards via advances in mapping and localization algorithms, and autonomous ground robot navigation and ear height measurement in corn fields. Thrust 2 continued to achieve milestones in power and communication for precision Ag infrastructure, including the demonstration of biodegradable batteries with extended lifetimes (up to 240 days), the development of a dual-function positioning and communications approach, deployment of the Avena communication framework to multiple testbeds. Thrust 3 researchers demonstrated the use of fused UAV and satellite datasets to detect water stress in sorghum, integrated weather and soil repository as well Avena data streams into data-driven biophysical models, and identified trust as a key for technology adoption among a diverse group of end users. Many of these milestones were achieved by deploying and assessing

technologies in IoT4Ag Joint Ops and testbeds. Activities in the Joint Ops continued to expand in Year 4 and have established a path for deployment and testing of integrated systems.

Testbed/Joint Op research is coordinated and planned for by students and faculty in monthly "office hours" led by the IoT4Ag testbed leaders (Joint Op1 on nitrogen management led by Quinn at Purdue, Joint Op2 on water management led by Ehsani at Merced, Joint Op3 on disease and pest management led by Small at UF). In Year 4, 22 of 23 research projects operated in one or more of IoT4Ag's testbeds and participated in our Joint Ops. As Joint Ops are increasingly prioritized in Years 5+ (see **Section 4D. Convergent Research**), we will review and accept proposals of new Joint Ops using the same mid-Year feedback and end-of-Year cadence and process as used for our projects, allowing for guidance from IoT4Ag stakeholders and the identification of new critical issues. On a yearly basis, each Joint Op will establish a detailed test plan and milestones for the current growing season, along with a roadmap for integrating and assessing technologies from individual projects. Testbed/Joint Op activities, as well as cross-project collaborations, require people and things to travel between (places) universities and to agricultural facilities at extension campuses. The Center established the Intra-ERC Technical Exchange (ITEX) program to provide travel funds to support our cross-institutional collaborative and Joint Ops research and cross-institutional educational opportunities, part of EDUCATE for an Inclusive World. 19 projects have completed travel at the time we are writing this report, much of the Center travel is coordinated with the growing season. As a Center we like to say, toward achieving our vision, "***IoT4Ag will deliver more crop for every drop of water and Joule of energy to ensure a food, energy, and water secure future.***"

Engineering Workforce Development (EWD) and Diversity & Culture of Inclusion (DCI): IoT4Ag **EWD** and **DCI** programs and activities are inseparable. In Year 4, in response to the NSF SVT report and with guidance from our advisory boards, we undertook an evaluation of the structure, function, and integration of our EWD and DCI programs and activities. We created an Action Plan to ensure intentionality of our programs and to deliver on our goals. We established a new Director of Education and Inclusivity position and hired Dr. Kristin Field, who has 11 years of experience leading education and inclusion programs for multi-PI NSF grants. We also formed a singular EWD-DCI advisory board that operates as one in meeting and providing guidance to the Center. Under Field's leadership, the Center executed the strategic integration and implementation of IoT4Ag's Action Plan for EWD and DCI programs. We introduced the **IoT4Ag Empowering People Portfolio**, we call for short, **IoT4Ag E^3**: **EXCITE** - Tech Meets Ag, exciting youth and the general public audiences about STEM and agriculture; **EDUCATE** for an Inclusive World, preparing student and postdoctoral trainees for rewarding careers in STEM and Ag; and **ENABLE** Professional Advancement, advancing the careers and accelerating the practice and/or pedagogy of professionals (**Fig. 4B.2, bottom**). **IoT4Ag E^3** provides programs and a structure to "**grow people**" and **catalyze systemic change** in agricultural and educational practice. IoT4Ag is creating, sustaining, and promoting a diverse workforce able to discover, innovate, translate, and practice precision agriculture solutions.

Each year we also create roadmaps, annual milestones, and 10-Year milestone charts to assess and ensure IoT4Ag EWD and DCI programs meet Center goals. In Year 4, with the launch of IoT4Ag E^3, we created a single collaborative set of charts to show how the Portfolio of EXCITE, EDUCATE, and ENABLE deliver on the EWD and the DCI logic models. The new joint milestone tables reinforce the connectivity of the EWD and DCI foundational components, as well as how the IoT4Ag E^3 portfolio scaffolds IoT4Ag's commitment and efforts to ***train and educate a diverse***

workforce. IoT4Ag E^3 EXCITE activities met their milestones for the deployment and reach of K12-focused robot and sensor lesson plans to diverse audiences, and for hosting six new teachers in the RET program, who join the 2022 alums with capacity to tailor and deploy IoT4Ag-based lessons in their schools, which serve diverse, economically disadvantaged student populations. EDUCATE activities for community college through postdoctoral fellows continue to provide research and professional development programming for its IoT4Ag graduate students and postdocs and undergraduate researchers (including summer REU students); professional development programming, like the Boot Camp, Annual Retreat and monthly Center meetings continue to play critical roles for cultivating inclusion and belonging. For EDUCATE audiences who are not matriculated in our IoT4Ag institutions, we continue our community college engagement, sponsorship of booths and demonstrations at minority-focused events, and the Pathway to PhD Program, which is one of our signature initiatives for making graduate school applications and funding more accessible through near-peer mentoring. EDUCATE milestones were met or exceeded except in the case of the number of trainee Intra-ERC Technical Exchanges (8 v 10) and for the number of minority-focused events (4 v 5). We will be encouraging trainees, especially new ones, to take advantage of the ITEX program. As part of our planned Year 5 deep analysis of our broadening participation activities, we will be looking at aligning our capacity to optimize IoT4Ag E^3 efforts for the highest quality diversity and inclusion outcomes. ENABLE activities met or exceeded their milestones, with 41 Ag practitioner-focused events and 15 events for inclusion of a diversity of growers and practitioners. Another IoT4Ag signature initiative, ENABLE's MSI-HBCU Partners Network Program, launched with two faculty in residence, one who brought a student.

Innovation Ecosystem: The IoT4Ag Innovation Ecosystem is structured along the axes of industry partnerships, stakeholder engagement, and culture of innovation (**Fig. 4B.2**). Industry partnerships are represented by the ERC industrial/practitioner advisory board (IPAB) of industry, venture, non-profit, and innovation partners. Stakeholder engagement includes interactions with farmers (extension presentations, field days, exhibits) as well as a formal body unique to IoT4Ag, the Ag-systems advisory board (ASAB), comprising the voices of the end-user community including farmers/growers, Ag professionals (crop consultants and extension agents), grower associations, and government entities. The IPAB and ASAB meet and provide guidance together. Industry partners and Stakeholders balance "tech push" vs. "industry pull" and guide the direction of Center ***research***, ***engineering workforce development***, and ***diversity & culture of inclusion*** activities. Culture of innovation brings all Center members together to support the continuum of idea creation to translation, from educational programming by our two IoT4Ag Entrepreneur Mentors to facilitation of IoT4Ag tech transfer through innovation competitions to small business formation and commercialization.

In response to the Year 1 SVT report, like in all ERC foundational components, the ***innovation ecosystem*** component structured a roadmap to describe the annual cadence of engagement for industry partners and IoT4Ag stakeholders and for innovation activities. Innovation Ecosystem also defines annual milestones and a 10-Year milestone chart, to meet the outputs and outcomes of the ***innovation ecosystem*** Logic Model. In Year 4, IoT4Ag met or exceeded nearly all annual milestones. The Center added 2 small and 1 medium size companies to the IPAB and 2 new members to the ASAB, through the end of Summer 2023. We also formalized stakeholder engagement with a new research-based approach/project, collaborating with other research projects and cross-cutting EWD, DCI, and the innovation ecosystem. This holistic approach

enhances stakeholder engagement, identifies key leaders for engagement, facilitates ENABLE professional advancement, and establishes a unified Outreach and Engagement Plan.

IoT4Ag Evaluation: At the start of Year 3, we replaced our external evaluator with Prof. Ayesha Boyce, ASU. Boyce has strong experience in working with large NSF Centers and is expert in using a Values-Engaged, Educative evaluation approach (VEE) (Boyce, 2017; Greene, DeStefano, Burgon, & Hall, 2006), a type of culturally responsive evaluation, developed with NSF – Education and Human Resources support. VEE defines high-quality STEM educational programming as that which effectively incorporates cutting-edge scientific content, strong instructional pedagogy, and sensitivity to diversity and equity issues. The VEE evaluation approach, which has over 15 years of field tests in STEM contexts (Boyce & Rivera, 2023), encourages explicit attention to issues of diversity and equity, and responsiveness to the culture and context of the program. Boyce and her team have conducted surveys and focus groups of Center programs and participants, across all four ERC foundational components – ***research, workforce development, diversity and culture of inclusion, and innovation ecosystem***, and are providing valued feedback and information as we continually work to improve the Center and achieve our goals.

CONVERGENCE

The IoT4Ag vision, mission, and strategic plan, described above, necessitates a convergence of disciplinary, institutional, professional, and demographic diversity. The Center brings together all of these diverse identities in its team of faculty, staff, students, advisory board members, and broadly speaking, our stakeholders. Our disciplinary expertise unites knowledge and tools from the fields of agronomy, agricultural engineering and economics, and environmental and social sciences with the science and engineering of physical and cyber systems. Our institutions include our core partner universities, and those of all of our advisory boards, partners, and stakeholders in engineering workforce development, diversity & culture of inclusion, and innovation ecosystem. Our institutions span the northeast, southeast, midwest, and west of the United States, as well as the world, representing a diversity of people, cultures, climates, cropping systems, and regulatory environments. Our members and stakeholders are from academia, government, and companies of various sizes and at different stages of and in different careers, and of course, as individuals, bring their individual perspectives, experiences, and identities.

The Center supports close collaboration of all of our members and stakeholders, through their engagement in and the structure of our projects, meetings, programs, and activities, which we describe through examples:

- Research projects are carried out by teams that span institutions and disciplines. The projects have SAB, IPAB, and ASAB project liaisons that advise on research and projects collaborate with one another particularly in the testbeds and through Joint Ops. Research collaboration in the center is facilitated by our meetings (e.g., Center-wide, Thrust, and Testbed Office Hours), our Annual Retreat that rotates across our universities, extension centers, and industry/farmer facilities and fields, and by our ITEX travel funds. Researchers learn from each other at our meetings and through our activities such as the Annual Retreat and NSF Site Visit poster sessions, the student-led Boot Camp programming, the IoT4Ag Seminar series, and JointOp panels.
- Meeting the Center mission "***to train and educate a diverse workforce***" requires a convergence of people who participate in the Center as core-partner faculty, staff, and students; as members

of all four ERC foundational component advisory boards; and as stakeholders from our partners in education, inclusion, and innovation. These Center participants bring a diversity of expertise and interests; are educators and learners, and often educators in one context and learners in another. IoT4Ag E^3 Enabling People Portfolio brings participants together with programs that are designed, developed, and deployed for specific audiences, whether pre-college, university, or professional learners and stakeholders (see **Fig. 4B.2** for a summary of key programs). These programs and other activities (e.g., lessons, demos, research experiences, meetings, seminars, workshops, the Boot Camp and Annual Retreat) engage participants, facilitate knowledge exchange, and build a synergistic community.

STAKEHOLDER ENGAGEMENT

IoT4Ag stakeholders include all four ERC foundational component advisory boards and councils and educational, inclusion, and innovation participants.

IoT4Ag maintained the following advisory boards and councils in Year 4: Scientific Advisory Board (6 members), a newly joined EWD-DCI Advisory Board 12 members, plus a Student & Postdoc Leadership Council representative, and Industrial Practitioner Advisory Board (21 member organizations) + Ag-Systems Advisory Board (19 members), Student & Postdoc Leadership Council (9 members), and the Council of Deans (4 members). This year one scientific advisory board member, Chandra Krintz (UCSB) stepped down and we recruited Nancy Amato (University of Illinois Urbana-Champaign) to take her place, who is starting in Year 5. The Center recruited 3 new IPAB and 2 new ASAB members to guide IoT4Ag research and engage in our programs. In response to the Year 3 SVT report, as indicated above, the EWD and DCI advisory board members joined to form the EWD-DCI Advisory Board, which meets and guides the Center as a single body. The IPAB and ASAB also have joint meetings and collaborate in our governance structure though the industrial practitioner executive committee (IPEC). Each Board has a Board Chair, enabling Center leadership to work more closely with interested Board Members and who serve as liaisons to the broader Board membership on behalf of the IoT4Ag team.

In Year 4, IoT4Ag Project 34_ENGAGEMENT, led by UF Department of Agricultural Education and Communication, was initiated after starting in Year 3 as a seed effort. Project 34 is a social science project spanning ***engineering workforce development***, ***diversity & culture of inclusion***, and ***innovation ecosystem*** foundational components focused on stakeholder engagement, to build long-term, trusted relationships primarily with end-user farmers, using evidence-based approaches designed in concert with farmers and evaluated for impact. Project 34 held webinars; exhibited at conferences, field days, and community events; and created a guide and submitted a peer-reviewed article on engagement. Project 34 closely collaborates with ***convergent research*** Project 28_TECH ADOPTION to support farmer engagement and the IoT4Ag TRL and ARL rubric/evaluation.

TEAM FORMATION

The vision and strategic plan require collaborative, multi-institutional, multi-disciplinary team formation. In the section above on convergence, we described the IoT4Ag programs and activities that serve to bring together and support team formation and continued collaboration across all ERC foundational components. The IoT4Ag faculty, staff, and students remained unchanged in Year 4, with one exception. To carry out our EWD-DCI Action Plan, we established a new Director of Education and Inclusivity position and hired Dr. Kristin Field (as described above). This position replaces the EWD and DCI Program Coordinator position in response to last year's NSF SVT report to elevate and develop and deploy our EWD and DCI strategic Action Plan.

INPUTS & RESOURCES	ACTIVITIES	OUTPUTS	OUTCOMES		
			KNOWLEDGE SHORT-TERM	ACTION MEDIUM-TERM	IMPACTS LONG-TERM
•NSF funding and ERC program resources •Excellent faculty; undergraduate, graduate, and postdoctoral Fellows; and staff •State-of-the-art individual and multi-user research and teaching facilities, campus educational and diversity offices, tech-transfer offices and incubators • Agricultural extension campuses with row and tree crop control, plots, and field and orchard-scale instrumented testing facilities, representing the diversity of crops and agricultural environments in the US •Existing and new relationships with diverse educational, industrial, and governmental, institutions and organizations inclusive of students, professionals, and the end-user community of growers •Scientific, EWD – DCI, Industrial/Practitioner + Ag-Systems Advisory Boards and Student Postdoc Leadership and Deans Councils	•Creation and integration of Ag-specific IoT technologies including sensors of plant and environmental targets, autonomous robotic fleet to map targets at field scale, sensor and robot energy devices, rural and agricultural communication networks, AI/digital twins of row and tree crops, human-centered decision-Ag interface for agricultural management •IoT4Ag E^3 education and inclusion programs: EXCITE creating and disseminating exhibits, kits, and lessons and building education and inclusion partnerships; EDUCATE introducing/providing courses, research experiences, mentorship, and professional development activities for college/university trainees; ENABLE delivering professional education activities and development of trust with end-user community •Research exchange and collaboration and student – faculty – industry – government professional networking *via* IoT4Ag meetings, newsletters, workshops, short courses, and webinars •IP creation and translation and adoption of IoT4Ag technologies and systems	•Fundamental knowledge, enabling technologies, and integrated sense-communication-response systems distributable at field scales for early detection and intervention to sustainably improve crop yield and resiliency •IoT4Ag E^3 outputs: EXCITE Lesson plans and activities for formal and informal education that are easily teachable, flexible, engaging, and adaptable to meet the needs of broad audiences, used by teachers and in partnership with schools/organizations; EDUCATE informational and educational materials, courses, research experiences and collaborations, and professional development activities that meet the needs and interests of broad audiences, and ENABLE talks, workshops, extension programs, crop advisor certification, tech demos, field days, exhibit booths in diverse, inclusive forums; MSI-HBCU faculty in-residency in IoT4Ag research labs •An engaged and vibrant IoT4Ag industry membership spanning the IoT for agriculture value chain and advancing/commercializing IoT4Ag tech; an engaged community of end-users in the Ag-systems advisory board; robust culture of innovation and IoT4Ag inventions and startups • IoT4Ag brand is known as a trusted partner in research, education, inclusion, and innovation with broad communities of stakeholders	•Cross-disciplinary education and collaboration to advance knowledge of plant, environmental, device, and data science/engineering •Create innovative sensor, robotic, power, and communication technologies and new biophysically-constrained models, controls, and software interfaces to advance Ag practices •IoT4Ag E^3 builds knowledge and inclusive culture in: EXCITE Understanding of best practices – What lessons/activities work in different settings, Who to train and How to deploy, How to collaborate with partners; developing and piloting of educational and inclusion programs; EDUCATE in understanding community college student academic and career paths; trainees and external students learn about opportunities and are engaged in, contributing to, and learn from Center research, academic, professional development activities; ENABLE growers, Ag practitioners and professionals to learn about IoT4Ag's mission, research, opportunities for participation and IoT4Ag to learn from stakeholders •Knowledge of technology requirements through guidance from our stakeholders composed of industry members, government and innovation partners, and growers	•Research builds and integrates technologies into systems that capture, communicate, and analyze a larger number of data streams, producing Ag-specific hardware and algorithms and openly sharing agriculture data sets •IoT4Ag E^3 EXCITE leads, makes web-accessible, and supports educators to use and build upon lesson plans/activities to meet audience-specific interests and needs; EDUCATE broadly includes and creates a supportive climate to engage community college, undergraduate and graduate students, and postdoctoral fellows in research, education and inclusion, and innovation programs; Trainees graduate, advancing their academic paths and secure positions; ENABLE is educating individual practitioners about and how to use new research and products/systems for farming; Foster and strengthen participation and early partnerships •IoT4Ag produces intellectual property disclosures, patent filings, and copyrights; engages IPAB in commercialization and student internships/hiring, and supports Center members in entrepreneurship yielding SBIR and investor backed start-up companies based on IoT4Ag technologies	•Multidisciplinary IoT4Ag Ag–Tech research is sustainable and growing, and broadens the impact of IoT in other sectors •IoT4Ag technologies are licensed by industry and startup companies; and its integrated systems are adopted by diverse groups of ENABLED end users, transforming agricultural practices •IoT4Ag E^3 EXCITE exposes and excites diverse K-12 and general public audiences to/by precision Ag and the grand challenge of food-energy-water security; IoT4Ag pedagogical tools serve as a resource used and disseminated in education and outreach activities by IoT4Ag and external organizations making agriculture and STEM academic and career paths exciting, welcoming, and full of opportunity; EDUCATE increases accessibility to education and prepares community college, undergraduate and graduate students, and postdoctoral fellows to pursue careers in and related to Ag-Tech with alums representing groups who have been underrepresented; ENABLE yields Industry-Academic-Government-NGO Partnerships for advancing Ag-Tech, including workforce training •IoT4Ag integrated systems realize increased and sustainable production of high-quality crops for greater US and global food security and higher profitability of farms

Figure 4B.4. Center-level Logic Model

ERC WEB TABLE 6: QUANTIFIABLE OUTPUTS

Table: Quantifiable Outputs					
Outputs	**Sep-01-2020 - Jun-30-2021**	**Jul-01-2021 - Jun-30-2022**	**Jul-01-2022 - Jun-30-2023**	**Jul-01-2023 - Jun-30-2024**	**All Years**
Publications Resulting From Core Funding					
In Peer-Reviewed Technical Journals	2	3	3	23	31
In Peer-Reviewed Conference Proceedings	3	2	8	15	28
In Trade Journals	0	0	2	0	2
With Multiple Authors:	5	3	12	37	57
Co-authored With ERC Students	2	1	10	27	40
Co-authored With Industry	0	0	0	0	0
With Authors From Multiple Engineering Disciplines	1	0	1	5	7
With Authors From Both Engineering and Non-Engineering Fields	0	1	1	6	8
With Authors From Multiple Institutions	2	2	0	6	10
Publications Resulting From Associated Projects in the Strategic Plan					
In Peer-Reviewed Technical Journals	12	11	11	4	38
In Peer-Reviewed Conference Proceedings	3	7	1	1	12
Publications Resulting From Sponsored Projects					
In Peer Reviewed Technical Journals	0	0	1	0	1
In Peer-Reviewed Conference Proceedings	0	0	1	0	1
Participating Organizations					
Industrial Practitioner Members	11	15	14	15	55
Innovation Partners	7	10	11	18	46
Funders of Sponsored Projects	0	0	0	0	0
Funders of Associated Projects	0	0	0	0	0
Contributing Organizations	0	0	0	0	0
ERC Technology Transfer					
Inventions Disclosed (by researchers or tech transfer office)	1	3	4	7	15
Total Patent Applications Filed	0	1	1	0	2
Provisional Patent Applications Filed [1]	0	1	1	0	2
Full Patent Applications Filed [1]	0	0	0	0	0
Patent Awarded	0	0	0	0	0
Licenses Issued	0	0	0	0	0
Spin-off Companies Started	0	0	0	0	0
Estimated Number of Spin-off Company Employees	0	0	0	0	0
Building Codes Impacts	0	0	0	0	0
Technology Standards Impacts	0	0	0	0	0

Outputs	Sep-01-2020 - Jun-30-2021	Jul-01-2021 - Jun-30-2022	Jul-01-2022 - Jun-30-2023	Jul-01-2023 - Jun-30-2024	All Years
New Surgical and Other Medical Procedures Adopted	0	0	0	0	0
Degrees to ERC Students					
Bachelor's Degrees Granted	4	3	3	7	17
Master's Degrees Granted	1	0	4	6	11
Doctoral Degrees Granted	3	4	7	6	20
Job Sector of ERC Graduates					
Undergraduates Hired by:					
Industry:	0	1	1	2	4
ERC Member Firms	0	0	0	0	0
Other U.S. Firms	0	0	1	2	3
Other Foreign Firms	0	1	0	0	1
Government	0	0	0	0	0
Academic Institutions	0	0	1	0	1
Other	0	0	0	0	0
Undecided/Still Looking/Unknown	4	2	1	5	12
Undergraduate ERC Graduates Total	4	3	3	7	17
Master's Graduates Hired by:					
Industry:	0	0	2	1	3
ERC Member Firms	0	0	0	0	0
Other U.S. Firms	0	0	2	1	3
Other Foreign Firms	0	0	0	0	0
Government	0	0	0	0	0
Academic Institutions	0	0	1	0	1
Other	0	0	0	0	0
Undecided/Still Looking/Unknown	1	0	1	5	7
Master's ERC Graduates Total	1	0	4	6	11
Ph.D.s Hired by:					
Industry:	3	2	3	4	12
ERC Member Firms	1	0	1	1	3
Other U.S. Firms	2	1	2	3	8
Other Foreign Firms	0	1	0	0	1
Government	0	0	1	0	1
Academic Institutions	0	2	1	2	5
Other	0	0	0	0	0
Undecided/Still Looking/Unknown	0	0	2	0	2
Ph.D. ERC Graduates Total	3	4	7	6	20

ERC Influence on Curriculum					
Outputs	**Sep-01-2020 - Jun-30-2021**	**Jul-01-2021 - Jun-30-2022**	**Jul-01-2022 - Jun-30-2023**	**Jul-01-2023 - Jun-30-2024**	**All Years**
New Courses Based on ERC Research That Have Been Approved by the Curriculum Committee and Are Currently Offered [2]	0	2	0	0	2
Currently Offered, ongoing Courses With ERC Content	0	2	0	1	3
New Textbooks Based on ERC Research	0	0	2	0	2
New Textbook Chapter Based on ERC Research	0	0	0	0	0
Free-Standing Course Modules or Instructional CDs	0	0	0	9	9
New Full-Degree Programs Based on ERC Research	0	0	0	0	0
New Degree Minors or Minor Emphases Based on ERC Research	0	0	13	0	13
New Certificate Programs Based on ERC Research	0	0	0	0	0
Total Full-Degree Programs Based on ERC Research	0	0	0	0	0
Number of Students Enrolled	0	0	0	0	0
Number of Students Graduated	0	0	0	0	0
Total Certificate Programs Based on ERC Research	0	0	0	0	0
Number of Students Enrolled	0	0	0	0	0
Number of Students Graduated	0	0	0	0	0
Active Information Dissemination/Educational Outreach					
Workshops, Short Courses, and Webinars [3]	15	21	22	15	73
Number of Participants That Attended Events	847	805	950	2591	5193
Innovation-focused Workshops, Short courses, Webinars, and Seminars	1	2	13	5	21
Number of Participants That Attended Events	63	555	1074	206	1898
Seminars, Colloquia, Invited Talks, Etc.	17	5	39	71	132
ERC Sponsored Educational Outreach Events for K-12 Students	0	11	9	13	33
Number of Students That Attended Events	0	915	1091	906	2912
Number of Teachers That Attended Events	0	2	59	5	66
ERC Sponsored Educational Outreach Events for Community Colleges	0	2	1	1	4
Number of Community College Students That Attended Events	0	25	25	25	75
Number of Community College Faculty That Attended Events	0	20	0	0	20

Outputs	Sep-01-2020 - Jun-30-2021	Jul-01-2021 - Jun-30-2022	Jul-01-2022 - Jun-30-2023	Jul-01-2023 - Jun-30-2024	All Years
ERC Sponsored Educational Outreach Events for Non-ERC Undergraduate Students	28	24	5	1	58
Number of Non-ERC Undergraduate Students That Attended Events	472	228	84	70	854
Number of Undergraduate Faculty That Attended Events	151	2	3	0	156
Personnel Exchanges					
Student Internships in Industry	2	3	6	10	21
Faculty Working at Member Firm	0	0	1	0	1
Member Firm Personnel Working at ERC	0	0	1	0	1

[1] Data for the breakdown of "Total Patent Applications Filed" into "Provisional Applications Filed" and "Full Patent Applications Filed" were not collected prior to 2013.
[2] New courses currently offered and approved by the curriculum committee are only counted in the first year that they are offered so there is no multiple counting of these courses.
[3] For years prior to 2009, the values include "Workshops and short courses to industry" and "Workshops and short courses to non-industry groups".
[4] Educational impacts/outreach activities may result from activities initiated as part of the ERC Engineering Workforce Development, Diversity and Culture of Inclusion, and Innovation Ecosystem programs.

ERC WEB TABLE 7: AVERAGE METRICS BENCHMARKED AGAINST ALL ACTIVE ERCS AND THE CENTER'S TECH SECTORS

Table: 2023 Average Metrics Benchmarked Against All Active ERCs and the Center's Tech Sector					
Metric	**Average All Active ERCs FY 2023**	**Average Micro/Optoelectronics, Sensing, and Information Technology Sector FY 2023**	**Average Class of 2020 FY 2023**	**IoT4Ag Total**	**IoT4Ag Total**
	(15 ERCs)	**(4 ERCs)**	**(4 ERCs)**	**FY 2023**	**FY 2024**
Organizations Within Non-Industry Sectors	**19**	**20**	**25**	**11**	**18**
Organizations Within Industry Sectors	**18**	**18**	**21**	**14**	**15**
Small	50%	35%	48%	64%	67%
Medium	4%	3%	5%	0%	0%
Large	46%	62%	48%	36%	33%
Industrial/Practitioner Member Firms	**16**	**11**	**20**	**14**	**15**
Innovation Partners	**11**	**7**	**14**	**11**	**18**
Funders of Sponsored Projects	**1**	**0**	**0**	**0**	**0**
Funders of Associated Projects	**6**	**9**	**11**	**0**	**0**
Contributing Organizations	**3**	**11**	**1**	**0**	**0**
Total Number of Organizations	**38**	**38**	**46**	**25**	**33**
Total Membership Fees Received	**$147,705**	**$236,875**	**$237,674**	**$163,500**	**$157,000**
Sources of Support [1]	**$5,171,749**	**$5,042,115**	**$8,711,845**	**$6,975,003**	**$7,403,998**
NSF	81%	86%	78%	86%	82%
Other Federal	1%	0%	0%	0%	0%
State Government	3%	0%	6%	0%	0%
Local Government	0%	0%	0%	0%	0%
Foreign Government	0%	0%	0%	0%	0%
Quasi-Government Research	0%	0%	0%	0%	0%
Industry (U.S. and Foreign)	6%	4%	3%	2%	2%
University (U.S. and Foreign)	10%	9%	12%	12%	16%
Other	0%	0%	0%	0%	0%
Associated Project Support	**$6,719,394**	**$10,798,164**	**$18,373,072**	**$5,301,728**	**$5,786,216**

Metric	Average All Active ERCs FY 2023	Average Micro/Optoelectronics, Sensing, and Information Technology Sector FY 2023	Average Class of 2020 FY 2023	IoT4Ag Total	IoT4Ag Total
	(15 ERCs)	(4 ERCs)	(4 ERCs)	FY 2023	FY 2024
ERC Personnel and Educational Participants	**2,680**	**2,921**	**3,222**	**1,382**	**1,019**
Leadership Team [2]	28	23	30	31	29
Faculty [3]	43	35	48	35	34
Graduate Students	68	69	83	73	80
Undergraduate Students	34	22	54	39	32
REU Students	13	12	15	23	28
Community College RET	0	0	0	0	0
K-12 Teachers (RET and non-RET)	9	11	3	6	6
K-12 Students (Young Scholars)	9	4	7	0	0
Faculty/Teachers That Attended ERC Sponsored Educational Outreach Events for K-12 Students [4]	327	188	162	59	5
Students That Attended ERC Sponsored Educational Outreach Events for K-12 Students [4]	2,116	2,504	2,795	1,091	805
Faculty That Attended ERC Sponsored Educational Outreach Events for Community Colleges [4]	7	21	1	0	0
Students That Attended ERC Sponsored Educational Outreach Events for Community Colleges [4]	25	33	24	25	0
% Women [5]	35%	25%	29%	28%	34%
% Underrepresented Racial Minorities [6]	13%	13%	7%	13%	17%
% Hispanic [6]	17%	10%	14%	12%	14%

Publications	Average	Average	Average	Total	Total
In Peer-Reviewed Technical Journals	26	24	24	3	19
In Peer-Reviewed Conference Proceedings	9	17	14	8	17
Multiple Authors: Co-Authored With ERC Students	29	36	35	10	24

Metric	Average All Active ERCs FY 2023	Average Micro/Optoelectronics, Sensing, and Information Technology Sector FY 2023	Average Class of 2020 FY 2023	IoT4Ag Total	IoT4Ag Total
	(15 ERCs)	(4 ERCs)	(4 ERCs)	FY 2023	FY 2024
Multiple Authors: Co-Authored With Industry	4	7	3	0	0

Intellectual Property	Average	Average	Average	Total	Total
Invention Disclosures	6	12	12	4	5
Patent Applications (Provisional and Full)	6	6	7	1	0
Patents Awarded	2	4	5	0	0
Licenses (patents, software)	0	0	0	0	0

Education and Outreach Outputs	Average	Average	Average	Total	Total
New Courses Developed	3	4	3	0	0
Currently Offered, Ongoing Courses With ERC Content	10	8	10	0	0
New Full Degree Programs	0	0	0	0	0
New Degree Minors or Minor Emphases	1	4	4	13	0
New Certificate Programs Based on ERC Research	0	0	0	0	0

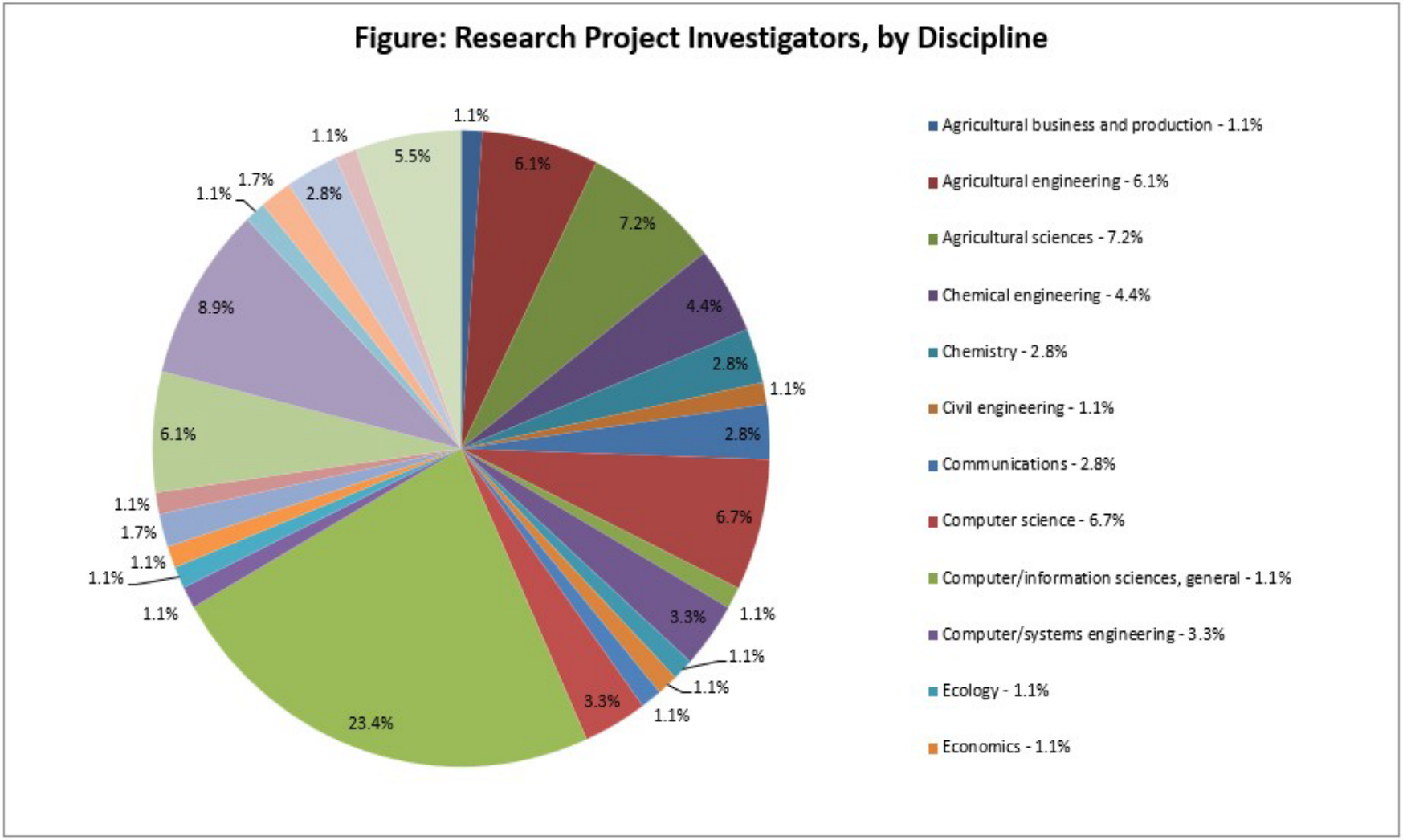
[1] - Includes new support (unrestricted cash, restricted cash, and in-kind donations) from Sources of Support Table only. Multi-year support and residual funds carried over from previous years are not included in benchmarking figures.
[2] - Includes Directors, Research Thrust Leaders, Engineering Workforce Development Program Leaders, Administrative Director, Innovation Ecosystem Program Leaders, Staff, Diversity and Culture of Inclusion Program Leaders and Student Leaders.
[3] - Includes Directors, Engineering Workforce Development Program Leaders, Research Thrust Leaders, Senior Faculty, Junior Faculty, and Visiting Faculty.

[4] - Includes participant values from Quantifiable Outputs Table.

[5] - Calculated out of total number of personnel.

[6] - Calculated out of total number of U.S. Citizens or Permanent Residents.
[7] - Educational impacts/outreach activities may result from activities initiated as part of the ERC Engineering Workforce Development, Diversity and Culture of Inclusion, and Innovation Ecosystem programs.

ERC WEB FIGURE 1: RESEARCH PROJECT INVESTIGATORS, BY DISIPLINE



4C. MANAGEMENT & ORGANIZATION

The Internet of Things for Precision Agriculture (IoT4Ag) Center is a partnership of four universities - - the University of Pennsylvania (Penn) (primary), Purdue University (Purdue), the University of California-Merced (Merced), and the University of Florida (UF). Arizona State University (ASU) leads the evaluation and assessment activities of the Center. All four partner universities and the external evaluation team at ASU work collaboratively to deliver IoT4Ag's vision using a strategic plan that depends on the work of the four foundational components, with the work of each foundational component delivered by the Center faculty, staff, and students & fellows from each of the partner institutions, guided by our advisory board and council members. Each foundational component uses an organizational structure (described below) that best matches the Center's activities, outputs, and intended outcomes.

LEADERSHIP TEAM

IoT4Ag is led by the Center Director, Cherie Kagan, and four Site Directors from each of the partner institutions, as follows: Kevin Turner (Penn), David Cappelleri (Purdue), Stefano Carpin (Merced), and David Arnold (UF). Two of the Site Directors also serve as co-leads to one of the following foundational components with Kevin Turner on **Convergent Research** and David Arnold on **Innovation Ecosystem**. This leadership team also includes Bob Brier, Administrative Director, and a new hire and IoT4Ag position, Kristin Field, Director of Education and Inclusivity. This new Director serves as one of the co-leads to both **Engineering Workforce Development** (**EWD**) and **Diversity and Culture of Inclusion** (**DCI**). The leadership team meets weekly to coordinate and ensure the timely and effective execution of the Center's activities across all four ERC foundational components and all four IoT4Ag universities.

Arizona State University conducts the **Evaluation and Assessment** activities for IoT4Ag, under the lead of Ayesha Boyce. Dr. Boyce is an Associate Professor of Educational Leadership and Innovation, with expertise in culturally responsive evaluation in STEM research. She has evaluated numerous large-scale NSF Centers and is an external evaluator for NSF-funded projects as well as an NSF co-investigator. With her students, she has successfully provided the evaluation and assessment services and reports to IoT4Ag.

FOUNDATIONAL COMPONENTS

The leadership team is part of the Executive Committee which oversees and is ultimately accountable for the success of IoT4Ag across foundational components and amongst and beyond our four campuses. The Executive Committee expands the team to include the Convergent Research co-Lead, James Krogmeier; Research Systems Integration Lead, Melba Crawford; the Evaluation & Assessment Director, Ayesha Boyce; and a Convergence team to represent the disciplinary and institutional diversity of the Center. The full Executive Committee meets quarterly, with additional meetings as needed, to review the Center activities and to plan and make decisions about upcoming milestones, tasks, and project selection.

The Directors/Leaders of the Center's foundational components are responsible for managing and collaborating within and across the components. The leaders work with participating faculty, staff, and students; pre-college, community college, and university partners and professional organizations; government, industry, and innovation partners; and growers, agricultural professionals, and grower associations to meet IoT4Ag goals. The foundational component

Leaders report to and are supported by the Center Director, the Site Directors, the Administrative Director, the Director of Education and Inclusivity, and the Industrial Liaison Officer.

As noted in the Organizational Chart (**Fig. 4C.1**), each foundational component is led by Directors or Leaders. The Convergent Research component is co-led by Kevin Turner (Penn) and James Krogmeier (Purdue), and Systems Integration Lead, Melba Crawford (Purdue). They work directly with our Scientific Advisory Board. The co-Leaders also partner with our Innovation Ecosystem Directors (described below) in working with stakeholders (i.e., our Industry Practitioner/Ag Systems Advisory Board) to delineate system expectations and requirements.

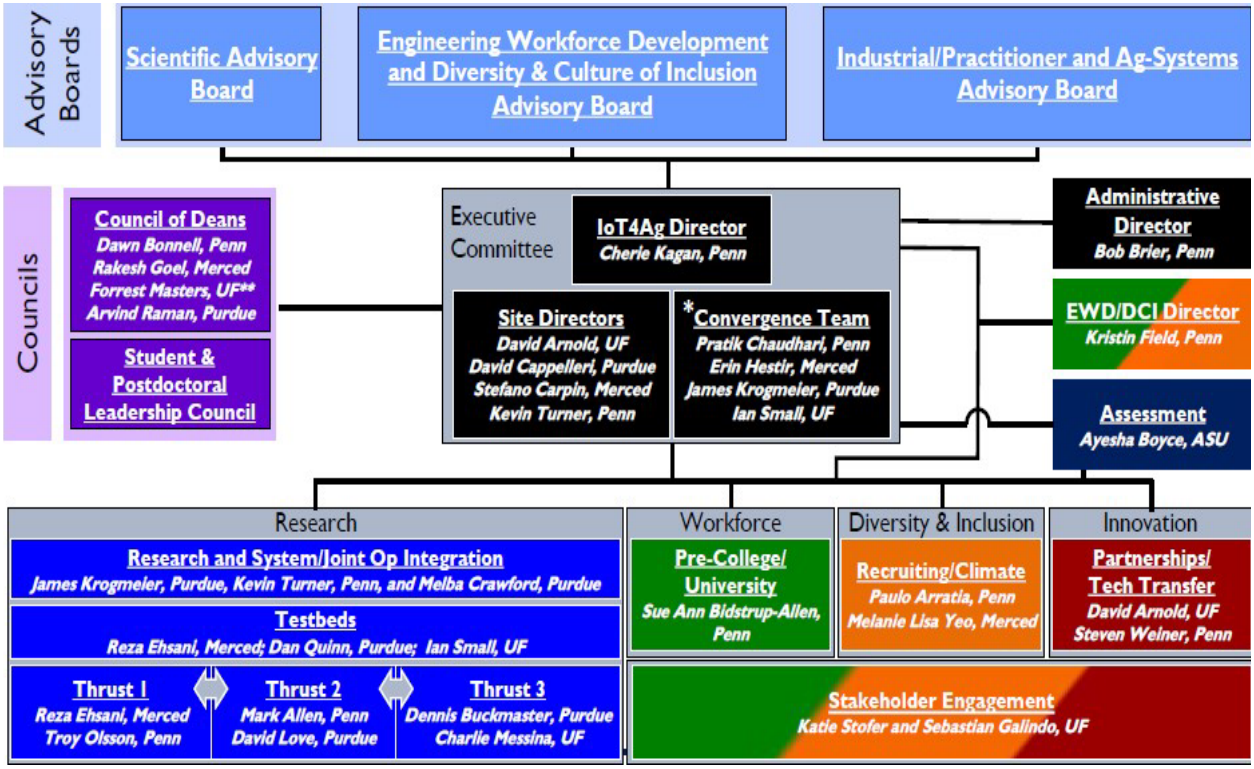


Figure 4C.1. IoT4Ag Organizational Chart of Leadership and Advisory Boards (June 2024).

These Leaders also collaborate with Thrust leaders, to coordinate research within and across thrusts, and with testbed leaders, to plan IoT4Ag systems deployment, our Joint Ops, and testing to verify they meet target specifications and thus, the need of the marketplace. Research Leaders for Thrust 1 include Reza Ehsani (Merced) and Troy Olsson (Penn), experts in sensors and robotics. Leading Thrust 2 is Mark Allen (Penn) and David Love (Purdue) who unite knowledge of energy and communication devices. Thrust 3 is co-led by Dennis Buckmaster (Purdue) and Carlos (Charlie) Messina (UF) who bridge know-how in AI digital twins and modeling and agricultural management systems. The Thrust Leaders are from different universities and from disciplines matched to the scope of the research, education, and innovation activities. Finally, the IoT4Ag testbeds are led by Reza Ehsani (Merced, UC Merced's new Experimental Smart Farm), by Ian Small (UF, North Florida Research and Education Center (NFREC)), and by Dan Quinn (Purdue, Agronomy Center for Research and Education (ACRE)).

EWD and DCI components are led by staff Director of Education and Inclusivity, Kristin Field. Field works with EWD co-lead Sue Ann Bidstrup Allen (Penn), DCI co-leads Lisa Yeo (Merced) and Paulo Arratia (Penn), and cross-component, Stakeholder Engagement co-leads (described

below) Katie Stofer and Sebastian Galindo (UF). These Leaders coordinate IoT4Ag's E^3 Portfolio of education and inclusion programs and activities: EXCITE youth and the lay public, EDUCATE trainees, and ENABLE established professionals. In Year 4, with the hiring of Kristin Field, the new Director of Education and Inclusivity, David Cappelleri stepped down as EWD co-lead.

Finally, the Innovation Ecosystem Leaders coordinate IoT4Ag inventions, commercialization, and engagement. David Arnold (UF) leads the industry and university partnerships, and Steven Weiner (Penn) serves as the IoT4Ag Industrial Liaison Officer and leads the technology transfer activities. In Year 4, Ian Small (UF) and Tony Vyn (Purdue), who is now retired, were replaced as EWD leaders of professional activities and Innovation Ecosystem leaders of professional engagement. In their place, Katie Stofer (UF) and Sebastian Galindo (UF), from the Dept. of Agricultural Education and Communication and experts in stakeholder engagement, K-12 Ag education program development, extension training, strategic planning, and program assessment, are serving as Leaders of Stakeholder Engagement, cutting across the EWD, DCI, and innovation ecosystem foundational components.

ADVISORY BOARDS AND COUNCILS

IoT4Ag works in partnership with the Councils and Advisory Boards to support the IoT4Ag mission, which are the following:

- Council of Deans
- Student and Postdoctoral Leadership Council (SPLC)
- Scientific Advisory Board (SAB)
- Engineering Workforce Development and Diversity & Culture of Inclusion Advisory Board
- Industrial/Practitioner and Agricultural Systems Advisory Board (IPAB / ASAB)

The **Council of Deans** is composed of partner University leadership (Dawn Bonnell, Penn (chair); Forrest Masters, UF; Arvind Raman, Purdue; and Rakesh Goel, Merced). Dawn Bonnell is the Vice Provost for Research and a Professor of Engineering at Penn. She serves on and chairs the Council, as Penn Engineering's Dean, Vijay Kumar is a member of the IoT4Ag faculty. Forrest Masters continues to serve as the Interim Dean of the College of Engineering at Florida. This Council continues to be committed to the collaborative success of IoT4Ag and is enthusiastically working with IoT4Ag Leadership to advise the Center on its research, integrated education and inclusion, and innovation programming. They help to ensure IoT4Ag's compliance with university, school, and departmental policies, support its plans, and promote its activities.

The **IoT4Ag Student and Postdoctoral Leadership Council (SPLC)** was formed from graduate students and postdoctoral fellows participating at all four partner universities. The SPLC is led by an elected President and Vice-President, from different universities and rotates annually. For Year 4, the SPLC president is Jun Xu (Penn) and the Vice President is Harsh Pathak (Purdue). The SPLC has taken up the leadership (with support from IoT4Ag faculty and staff) of DCI Triannual Check-ins (described in **Section 4D. Diversity & Culture of Inclusion**) and of the student "Boot Camp" in advance of the IoT4Ag Annual Meeting. SPLC members serve as liaisons to each of the foundational component's leadership and advisory boards and two of the partner campuses (UF and Merced). The SPLC also conducts a yearly SWOT analysis to give Center Directors student-oriented guidance of IoT4Ag research, education, inclusion, and innovation activities.

The **Scientific Advisory Board (SAB)** advises Center leadership, faculty, staff, and students on the Center's Convergent Research foundational component and its development of knowledge,

technology, systems, and testbeds. The SAB was selected from non-Center academic and government experts that represent the science, engineering, and socioeconomics needed for a convergent understanding of the impacts and opportunities of and the threats to physical and cyber system enabled precision agriculture. In Year 4, there was one change in the SAB membership: Chandra Krintz (UC Santa Barbara) stepped down due to schedule conflicts and Nancy Amato, Professor and Interim Director, Siebel School of Computing and Data Science at University of Illinois at Urbana-Champaign, accepted our invitation to serve on the SAB, starting in Year 5.

The **Engineering Workforce Development and Diversity & Culture of Inclusion Advisory Board (EWD-DCI AB)** was established in Year 4 upon merger of the EWD Advisory Board and the DCI Advisory Boards. The EWD-DCI AB operates as one with members meeting and providing guidance jointly. The newly combined board consists of academic experts, including Associate Deans for education from our universities, external faculty with formal training and research in engineering education, representatives from diversity and inclusion offices from each partner university, and external faculty leading diversity and inclusion activities on their campuses. In addition, the SPLC liaisons participate in the advisory board meetings. This advisory board guides the Engineering Workforce Development and Diversity & Culture of Inclusion leadership.

The **Industrial and Practitioner Advisory Board (IPAB) + Agricultural Systems Advisory Board (ASAB)** remain distinct entities, given their different membership fees and benefits, but also now meet and provide guidance jointly. The IPAB includes representatives designated by each of the industry, venture, non-profit, and innovation partners. The ASAB comprises voices of the end-user community and includes farmers/growers and representatives from farming associations, commodity producer boards (row, vegetable, fruit, and nut crops), crop consultant associations, farm cooperatives with precision Ag advisors, Ag and horticulture extension agents, and government entities. Notably, the IPAB maintains the benefits of fee-paying members and is advising IoT4Ag on pathways for commercialization and IoT4Ag Business and Sustainability planning. The IPAB/ASAB members elect an Industrial/Practitioner Executive Committee (IPEC) and an elected chair, to serve as the voice of all members of the IPAB. The IPAB/ASAB work intimately with Innovation Directors Arnold (UF) and Weiner (Penn), and the Executive Committee. A detailed list of the growing IoT4Ag IPAB and ASAB membership is included in **Section 4G. Innovation Ecosystem**.

All advisory boards provide formal guidance to IoT4Ag at least twice yearly (as depicted in the four foundational component roadmaps describing the cadence of IoT4Ag activities and self-evaluation) and perform an annual SWOT analysis of the IoT4Ag value proposition. Advisory board members are also invited to the IoT4Ag in-person Annual Retreat and virtual Center-wide meetings, workshops, and seminars. In Year 4, members from all advisory boards were invited to attend the Retreat at the University of California - Merced, either in-person or virtually, to serve as guest panelists and breakout session presenters. The detailed structures of the Councils and Boards are described in their respective Charters (**Appendix IV**). The Councils and Boards advise, support, and two-way report to/from the IoT4Ag Executive Committee.

MANAGEMENT OF MILESTONES, PROGRESS AND SUSTAINED IMPACT

In Year 2, IoT4Ag constructed roadmaps, which lay out our deliberate plans, (i.e., the cadence and scope of activities), that detail the management structure and processes of each ERC foundational component and their collaborations. Each foundational component also creates yearly milestones to prioritize, challenge, and meet its goals, which are planned to make and allow evaluation and

revision, as needed, to each IoT4Ag component's short, medium, and long-term objectives. Each component's objectives are detailed over the 10 years of planned NSF support in their 10-Year milestone charts and logic models, which were constructed in concert to serve the IoT4Ag strategic plan and to position the Center to be self-sustaining after the 10 years of NSF support. In Year 4, IoT4Ag executed on its management plans and systems. The roadmaps, Year 4 milestones, 10-Year milestone charts, and logic models for each foundational component are presented and the management systems are described in detail in **Sections 4D-G**.

Briefly, programs and projects are selected to serve the strategic plan and are prioritized by the foundational components based on the guidance from the appropriate advisory board(s) and the evaluation of the Executive Committee. The ***convergent research*** component has a detailed and formal process for research updates and reporting of ongoing projects, at mid-year to provide feedback and allow for adjustments, and at the end-of-the-year to provide feedback and make decisions on selection/renewal, revision, or termination. The research component also has a call at mid-year to encourage/discourage new projects based on their alignment with the strategic plan and to provide feedback to strengthen proposals that are submitted at the end of the year for formal evaluation and a decision on selection. The SAB and IPAB+ASAB members are invited to participate in the mid-year feedback and the end-of-the-year review, to guide the prioritization and selection of projects for the following year. This process was fully executed in Year 4. As Joint Ops are increasingly prioritized in Year 5+ (see **Section 4D. Convergent Research**), we will review existing and accept proposals of new Joint Ops using the same mid-Year feedback and end-of-Year cadence and process as used for our projects, allowing for guidance from IoT4Ag stakeholders and the identification of new critical issues.

For Year 4, funding allocations followed the IoT4Ag review process described above and detailed in the IoT4Ag ***convergent research*** roadmap. The allocation of research funds is made based on budgets submitted with renewal or new project proposals, the evaluation of the budget suitability, and the prioritization of projects based on the review process.

Program/project quality is assessed at the end of the year against foundational component yearly milestones and as part of the work of the independent IoT4Ag Evaluator. As described above, all IoT4Ag advisory boards and the SPLC carry out a year-end SWOT analysis as part of our Center self-assessment. The SWOT analyses and recommendations are forwarded to the foundational component leaders for their consideration and response and then the response is forwarded back to each advisory board. The engagement and formal SWOT analyses of IoT4Ag advisory boards are excellent at identifying and making connections with associated programs and projects. The SWOT reports and responses for Year 4 have been uploaded to the NSF SharePoint site.

NEW FOR THIS REPORTING PERIOD

- One staffing change to note is that in restructuring to add the new and elevated Director of Education and Inclusivity position, the position of EWD/DCI Coordinator previously held by Domonique McClendon was discontinued.
- Tony Vyn, Purdue Testbed leader, retired this past year and was replaced by Dan Quinn, Purdue.
- The Convergence team is a rotating body to broaden technical, institutional, gender/racial, and include early career faculty participation in the Executive Committee. This past year, Erin Hestir replaced Stefano Carpin as the Merced representative as Stefano stepped into the role

as the Merced Site Director and Pratik Chaudhari replaced George Pappas at Penn as George Pappas stepped down as a member of IoT4Ag.

- Dave Cappelleri no longer serves as one of the EWD Leaders but remains Purdue's Site Director. The new Director of Education and Inclusivity, Kristin Field, has taken on this role for EWD.
- Jim Krogmeier shares the role of the Convergent Research lead with Kevin Turner to add expertise to the component leadership.
- The SPLC rotates its membership each year, with Jun Xu (Penn) as the new SPLC president and Harsh Pathak (Purdue) as the new SPLC vice president.
- Chandra Krintz stepped down from the Scientific Advisory Board and was replaced by Nancy Amato from the Siebel School of Computing and Data Science at University of Illinois at Urbana-Champaign.

RESPONSE TO SWOT

The section below responds to last year's NSF site visit SWOT.

Threats:

- The large and complicated administrative infrastructure, and the way it is structured seems to take a lot of time and effort from researchers and leadership and hinder a smooth-running ERC. Communication strategies should be evaluated to understand information flow.

RESPONSE:

We appreciate the SVT feedback on the size and complexity of the administrative infrastructure. In Year 4, we have simplified our structures and restructured staff to support Center operations. Notably, in consultation with our advisory boards, we merged the EWD and DCI advisory boards. The merged board meets and provides guidance jointly. The IPAB and ASAB, while distinct given the difference in their member benefits/fees, also meet and provide guidance as one body. We also restructured our staff, hiring a new Director of Education and Inclusivity, Dr. Kristin Field, who brings 11 years of experience in education and inclusion leadership in NSF Centers. Field provides strong leadership across EWD and DCI foundational components, and with Brier, Administrative Director, and Weiner, Innovation Ecosystem co-lead and ILO, there is excellent staff support across the Center.

We strengthened the use of Slack as the IoT4Ag communication tool, encouraging faculty and students to communicate outside of email across the Center. We streamlined the Slack channels for specific groups, including the student leadership groups. Originally, the student leadership council established an independent Slack group, and therefore this Slack membership and activity was not captured in the IoT4Ag usage and statistics. At the request of the SLC (now SPLC), we have brought the student Slack channels within IoT4Ag to facilitate student effective and efficient communication and to better capture that data for reporting purposes.

We continue to evaluate the frequency and timing of administrative work requests to lower their burden and frequency. In Year 4 we organized Center-wide meetings for consistent timing and to reduce the # of meeting days, e.g., 1st Friday for the monthly seminars, 2nd Friday for the thrust and testbed meetings, and 3rd Friday for Center-side meetings. We keep the 4th Friday clear to allow for a day off from IoT4Ag meetings.

We will continue our weekly Monday event notice email, sent via MailChimp, to inform all members of upcoming meetings and events as well as job and internship opportunities, IoT4Ag social media links, ITEX application procedures, and other useful links and information.

ERCWEB TABLE 8: INSTITUTIONS EXECUTING THE ERC'S RESEARCH, TECHNOLOGY TRANSFER, AND EDUCATION PROGRAMS

Table: Institutions Executing the ERC's Research, Technology Transfer, and Education Programs Institutions						
Name and Type	**Total**	**Female Serving**	**Minority Serving**	**HBCU**	**Hispanic Serving**	**Large Number of URM Students in Engineering**
I. Lead	**1**	**0**	**0**	**0**	**0**	**0**
University of Pennsylvania, Philadelphia, PA						
II. Core Partners	**3**	**0**	**0**	**0**	**1**	**0**
Purdue University, West Lafayette, IN						
University of California, Merced, Merced, CA					✔	
University of Florida, Gainesville, FL						
III. Foreign Partners	**0**	**0**	**0**	**0**	**0**	**0**
No Foreign institutions were entered.						
IV. Collaborating Institutions	**12**	**0**	**4**	**1**	**0**	**0**
4-H Science and Adventure Camp, West Lafayette, IN						
AgrAbility, West Lafayette, IN						
Arizona State University, Tempe, AZ						
CalTeach, Berkeley, CA						
Center for Information Technology Research in the Interest of Society (CITRIS), Merced, CA						
Community Alliance of Family Farmers, Madeira, CA						
Deaf Kids Code, West Lafayette, IN			✔			
Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS), Atlanta, GA			✔			

Name and Type	Total	Female Serving	Minority Serving	HBCU	Hispanic Serving	Large Number of URM Students in Engineering
Pennsylvania Agriculture Cross-Sector Collaborative, Harrisburg, PA						
Tuskegee University, Tuskegee, AL			✔			
University of Maryland Eastern Shore, Princess Anne, MD			✔	✔		
Walt Disney World, Lake Buena Vista, FL						
V. Non-ERC Institutions Providing REU Students	**23**	**0**	**1**	**0**	**4**	**1**
California Polytechnic State University San Luis Obispo, San Luis Obispo, CA			✔			
Grinnell College, Grinnell, IA						
Illinois Institute of Technology, Chicago, IL						
Merced College, Merced, CA					✔	
North Carolina State University at Raleigh, Raleigh, NC						
Northeastern University, Boston, MA						
Northwestern University, Evanston, IL						
Pennsylvania State University-Main Campus, University Park, PA						
Princeton University, Princeton, NJ						
Santa Clara University, Santa Clara, CA						
Santa Fe College, Gainesville, FL					✔	

Name and Type	Total	Female Serving	Minority Serving	HBCU	Hispanic Serving	Large Number of URM Students in Engineering
Stevens Institute of Technology, Hoboken, NJ						
Swarthmore College, Swarthmore, PA						
Syracuse University, Syracuse, NY						
The University of Texas at Dallas, Dallas, TX						
The University of Texas at El Paso, El Paso, TX					✔	
University of Illinois at Urbana Champaign, Champaign, IL						
University of Maryland Baltimore County, Baltimore, MD						
University of Pittsburgh, Pittsburgh, PA						
University of Puerto Rico at Humacao, Humacao, PR					✔	✔
University of Tennessee Martin, Martin, TN						
University of Texas at Austin, Austin, TX						
Villanova University, Villanova, PA						
VI. NSF Diversity Program Awardees	**0**	**0**	**0**	**0**	**0**	**0**
Alliances for Graduate Education and the Professoriate (AGEP)	**0**	**0**	**0**	**0**	**0**	**0**
No AGEP institutions were entered.						

Name and Type	Total	Female Serving	Minority Serving	HBCU	Hispanic Serving	Large Number of URM Students in Engineering
Centers of Research Excellence in Science and Technology (CREST)	**0**	**0**	**0**	**0**	**0**	**0**
No CREST institutions were entered.						
Louis Stokes Alliances for Minority Participation (LSAMP)	**0**	**0**	**0**	**0**	**0**	**0**
No LSAMP institutions were entered.						
Tribal Colleges and Universities Program (TCUP)	**0**	**0**	**0**	**0**	**0**	**0**
No TCUP institutions were entered.						
NSF Diversity Program Collaborations (NSF Diversity Program Collaborations)	**0**	**0**	**0**	**0**	**0**	**0**
No NSF Diversity Program Collaborations were entered.						
VII. Precollege Partners	**12**	**0**	**0**	**0**	**1**	**0**
BobCat Academy, Marshalltown, IA						
Cade Museum for Creativity and Invention, Gainesville, FL						
Future Farmers of America, Indianapolis, IN						
Hamilton West High School, Philadelphia, PA						
Kensington High School, Philadelphia, PA					✔	
Lankenau Environmental Science High School, Philadelphia, PA						
Lower Merion High School, Philadelphia, PA						
Morris Arboretum, Philadelphia, PA						

Name and Type	Total	Female Serving	Minority Serving	HBCU	Hispanic Serving	Large Number of URM Students in Engineering
National Agriculture in the Classroom, Gainesville, FL						
Science Leadership Academy at Beeber, Philadelphia, PA						
Student Science Training Program, Gainesville, FL						
W.B. Saul High School of Agriculture, Philadelphia, PA						
VIII. Community Colleges	**1**	**0**	**0**	**0**	**0**	**0**
Ivy Tech Community College of Indiana, Lawrenceburg, IN						
Total	**52**	**0**	**5**	**1**	**6**	**1**

	Personnel in ERC Activities [1]									
Name and Type	**Faculty**	**Community College RET**	**Teachers (K-12)**		**Postdocs**	**Students**				**Young Scholars**
			RET	**Non-RET**		**Graduate**		**UG Non-REU**	**REU**	
						Doctoral	**Masters**			
I. Lead	**10**	**N/A**	**N/A**	**N/A**	**6**	**23**	**10**	**7**	**1**	**N/A**
University of Pennsylvania, Philadelphia, PA	10	N/A	N/A	N/A	6	23	10	7	1	N/A
II. Core Partners	**23**	**N/A**	**N/A**	**N/A**	**5**	**38**	**5**	**25**	**1**	**N/A**
Purdue University, West Lafayette, IN	7	N/A	N/A	N/A	1	16	3	8	1	N/A
University of California, Merced, Merced, CA	5	N/A	N/A	N/A	1	9	0	8	0	N/A
University of Florida, Gainesville, FL	11	N/A	N/A	N/A	3	13	2	9	0	N/A

Name and Type	Faculty	Community College RET	Teachers (K-12)		Postdocs	Students				Young Scholars
			RET	Non-RET		Graduate		UG Non-REU	REU	
						Doctoral	Masters			
III. Foreign Partners	**0**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**0**	**N/A**
No Foreign institutions were entered.										
IV. Collaborating Institutions	**2**	**N/A**	**N/A**	**N/A**	**0**	**4**	**0**	**0**	**0**	**N/A**
4-H Science and Adventure Camp, West Lafayette, IN	0	N/A	N/A	N/A	0	0	0	0	0	N/A
AgrAbility, West Lafayette, IN	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Arizona State University, Tempe, AZ	1	N/A	N/A	N/A	0	4	0	0	0	N/A
CalTeach, Berkeley, CA	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Center for Information Technology Research in the Interest of Society (CITRIS), Merced, CA	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Community Alliance of Family Farmers, Madeira, CA	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Deaf Kids Code, West Lafayette, IN	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS), Atlanta, GA	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Pennsylvania Agriculture Cross-Sector Collaborative, Harrisburg, PA	0	N/A	N/A	N/A	0	0	0	0	0	N/A
Tuskegee University, Tuskegee, AL	0	N/A	N/A	N/A	0	0	0	0	0	N/A

Name and Type	Faculty	Community College RET	Teachers (K-12)		Postdocs	Students				Young Scholars
			RET	Non-RET		Graduate		UG Non-REU	REU	
						Doctoral	Masters			
University of Maryland Eastern Shore, Princess Anne, MD	1	N/A	N/A	N/A	0	0	0	0	0	N/A
Walt Disney World, Lake Buena Vista, FL	0	N/A	N/A	N/A	0	0	0	0	0	N/A
V. Non-ERC Institutions Providing REU Students	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**26**	**N/A**
California Polytechnic State University San Luis Obispo, San Luis Obispo, CA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A
Grinnell College, Grinnell, IA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Illinois Institute of Technology, Chicago, IL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Merced College, Merced, CA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A
North Carolina State University at Raleigh, Raleigh, NC	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Northeastern University, Boston, MA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Northwestern University, Evanston, IL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Pennsylvania State University-Main Campus, University Park, PA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Princeton University, Princeton, NJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A

Name and Type	Faculty	Community College RET	Teachers (K-12)		Postdocs	Students				Young Scholars
			RET	Non-RET		Graduate		UG Non-REU	REU	
						Doctoral	Masters			
Santa Clara University, Santa Clara, CA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Santa Fe College, Gainesville, FL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	N/A
Stevens Institute of Technology, Hoboken, NJ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Swarthmore College, Swarthmore, PA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Syracuse University, Syracuse, NY	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
The University of Texas at Dallas, Dallas, TX	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
The University of Texas at El Paso, El Paso, TX	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
University of Illinois at Urbana Champaign, Champaign, IL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
University of Maryland Baltimore County, Baltimore, MD	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
University of Pittsburgh, Pittsburgh, PA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
University of Puerto Rico at Humacao, Humacao, PR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
University of Tennessee Martin, Martin, TN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A

Name and Type	Faculty	Community College RET	Teachers (K-12)		Postdocs	Students				Young Scholars
			RET	Non-RET		Graduate		UG Non-REU	REU	
						Doctoral	Masters			
University of Texas at Austin, Austin, TX	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
Villanova University, Villanova, PA	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1	N/A
VI. NSF Diversity Program Awardees	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**
Alliances for Graduate Education and the Professoriate (AGEP)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**
No AGEP institutions were entered.										
Centers of Research Excellence in Science and Technology (CREST)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**
No CREST institutions were entered.										
Louis Stokes Alliances for Minority Participation (LSAMP)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**
No LSAMP institutions were entered.										
Tribal Colleges and Universities Program (TCUP)	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**
No TCUP institutions were entered.										
NSF Diversity Program Collaborations (NSF Diversity Program Collaborations)	**0**	**N/A**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**0**	**N/A**
No NSF Diversity Program Collaborations were entered.										

Name and Type	Faculty	Community College RET	Teachers (K-12)		Postdocs	Students				Young Scholars
			RET	Non-RET		Graduate		UG Non-REU	REU	
						Doctoral	Masters			
VII. Precollege Partners	**N/A**	**N/A**	**6**	**0**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0**
BobCat Academy, Marshalltown, IA	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
Cade Museum for Creativity and Invention, Gainesville, FL	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
Future Farmers of America, Indianapolis, IN	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
Hamilton West High School, Philadelphia, PA	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
Kensington High School, Philadelphia, PA	N/A	N/A	1	0	N/A	N/A	N/A	N/A	N/A	0
Lankenau Environmental Science High School, Philadelphia, PA	N/A	N/A	2	0	N/A	N/A	N/A	N/A	N/A	0
Lower Merion High School, Philadelphia, PA	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
Morris Arboretum, Philadelphia, PA	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
National Agriculture in the Classroom, Gainesville, FL	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
Science Leadership Academy at Beeber, Philadelphia, PA	N/A	N/A	2	0	N/A	N/A	N/A	N/A	N/A	0
Student Science Training Program, Gainesville, FL	N/A	N/A	0	0	N/A	N/A	N/A	N/A	N/A	0
W.B. Saul High School of Agriculture, Philadelphia, PA	N/A	N/A	1	0	N/A	N/A	N/A	N/A	N/A	0
VIII. Community Colleges	**0**	**0**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**0**	**N/A**
Ivy Tech Community College of Indiana, Lawrenceburg, IN	0	0	N/A	N/A	0	0	0	0	0	N/A
Total	**35**	**0**	**6**	**0**	**11**	**65**	**15**	**32**	**28**	**0**

[1] - Only ERC personnel executing the ERC mission are shown in this table.

[2] Faculty is calculated by counting all personnel associated with institutions that have one of the following attributes: Director, Research Thrust, Engineering Workforce Development Program Leaders, Programmatic Personnel Junior Faculty, Programmatic Personnel Senior Faculty and Programmatic Personnel Visiting Faculty.

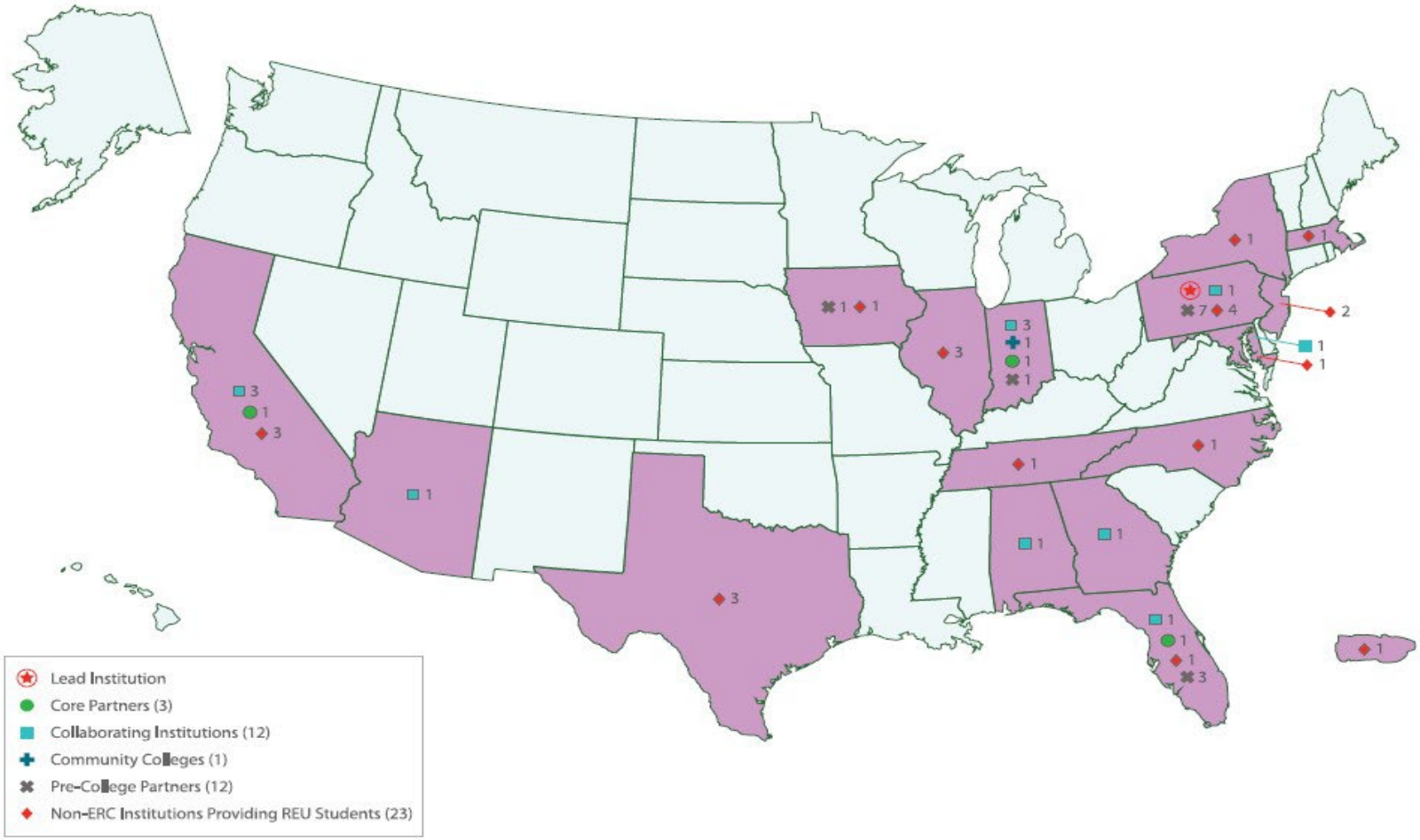
On the next three pages are the following ERCWEB figures:

ERCWEB FIGURE 2: LOCATION OF LEAD, CORE PARTNER AND ALL DOMESTIC COLLABORATING INSTUTIONS

ERCWEB FIGURE 3: LOCATION OF FOREIGN COLLABORATING INSTITUTIONS AND/OR FOREIGN PARTNER INSTITUTIONS

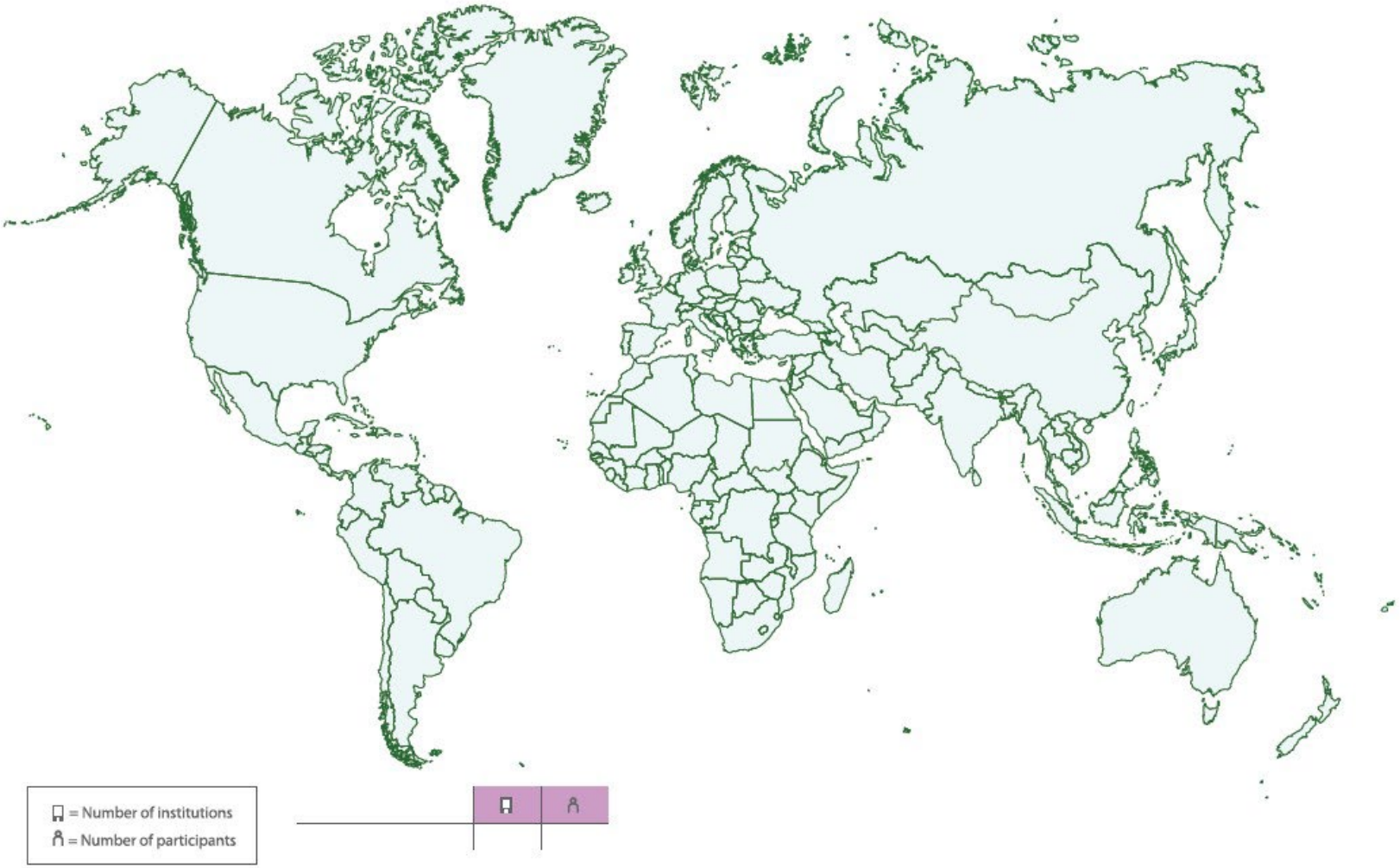
ERCWEB FIGURE 3: COUNTRY OF CITIZENSHIP FOR ERC FOREIGN PERSONNEL

Location of Lead, Core Partner, and All Domestic Collaborating Institutions



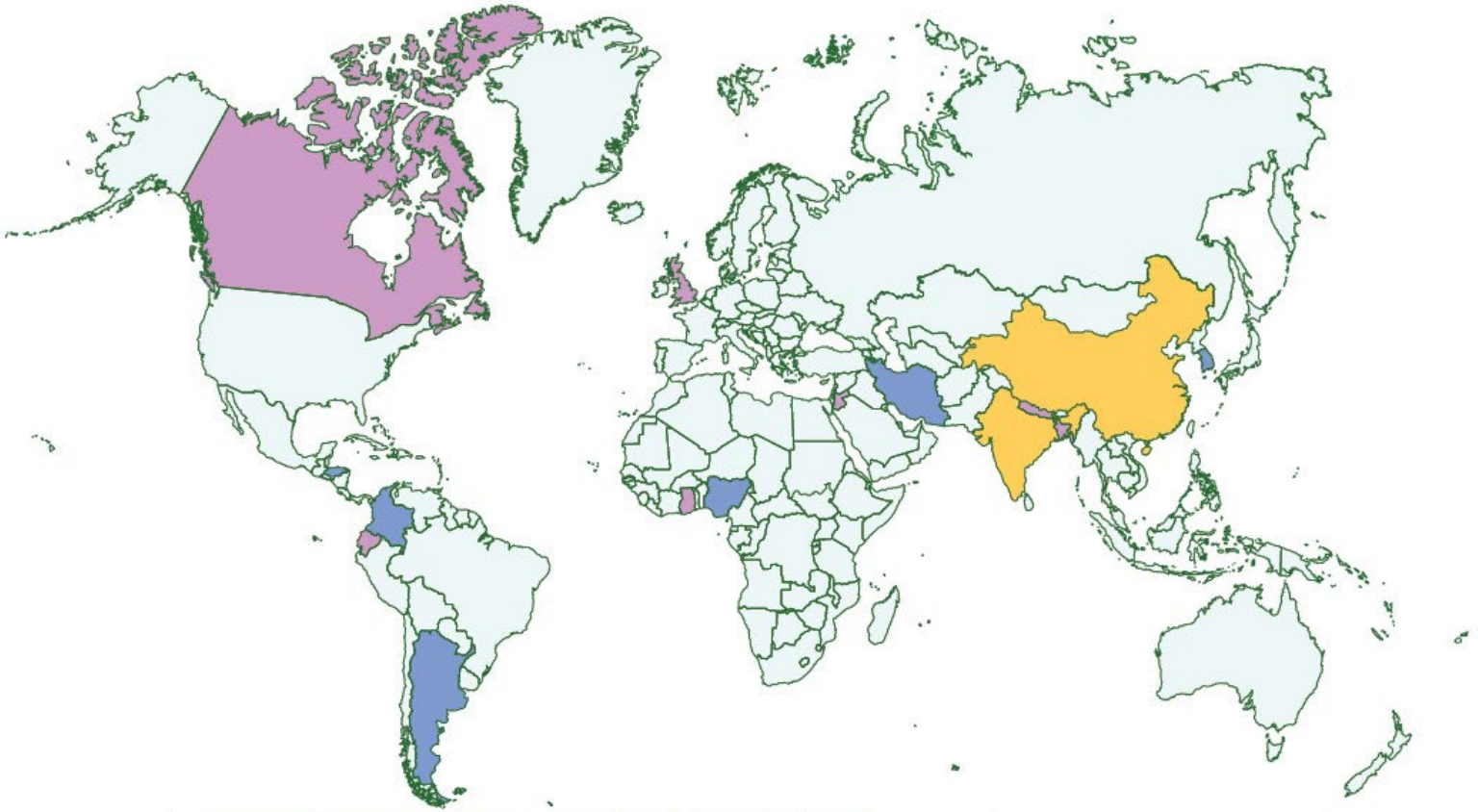
NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

Location of Foreign Collaborating Institutions and/or Foreign Partner Institutions



NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

Country of Citizenship for ERC Foreign Personnel



= Number of ERC personnel from this country

- 1 person
- 2–10 people
- 11+ people

1 person	
Bangladesh	Nepal
Canada	Singapore
Ecuador	United Kingdom
Ghana	
Jordan	
Lebanon	

2–10 people	
Argentina	2
Colombia	4
Honduras	2
Iran	6
Nigeria	2
South Korea	2

11+ people	
China	15
India	18

Country Not Reported	0*

* Number of ERC personnel who are foreign and did not provide a country name

4D. CONVERGENT RESEARCH

OVERVIEW

IoT4Ag's research program aims to transform agriculture today and create integrated systems to realize the farm of the future. Today, agricultural crop monitoring is still accomplished largely through the expensive, labor-intensive, and time-consuming process of crop scouting, manual sampling and documenting the state of the field. Precision agriculture involves the use of technology to acquire and analyze data from the field. While the concept of precision agriculture has existed for more than 30 years, current sensor technologies are inadequate to monitor the state of the field spatially, temporally, and compositionally, data is coarse-grained and siloed in equipment, communications infrastructure is limited or non-existent on the farm, and interventions are reactive and over-provisioned, increasing economic cost and environmental impact. IoT4Ag is built on the idea that the *exponential growth in information technology and data science and the reduction in their cost is setting the stage for the next revolution in agricultural practices.*

IoT4Ag is creating next-generation IoT sense-communication-response technologies and establishing engineered integrated systems for precision farming of tree crops and row crops, mainstays of the food supply chain. The Center's research is driven by the agricultural-specific use case of IoT to achieve breakthroughs in sensors, robotics, energy and communications, AI-driven digital twins of row and tree crops, and human-centered Ag-decision interfaces for agricultural management. Integrated systems engineered from these technologies are being designed to capture the microclimate and spatially, temporally, and compositionally map heterogeneous stresses for early detection and intervention to ensure sustainable agricultural crop production with reduced environmental impact and improved yield.

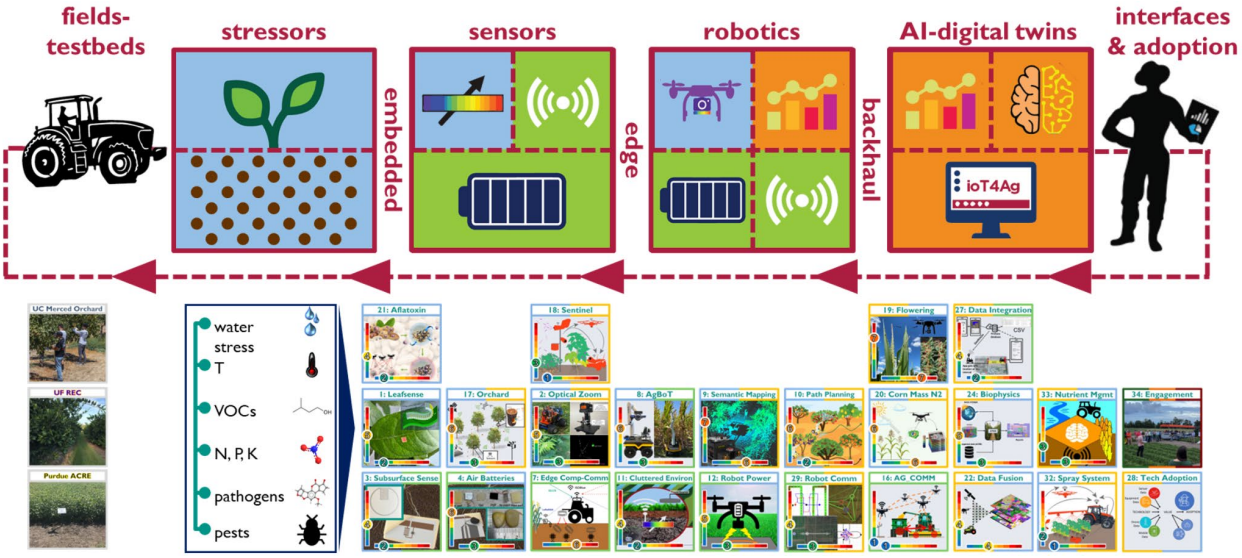


Figure 4D.1 "Flow" or "Wiring" diagram (from left to right) portraying the IoT4Ag integrated systems in the farm of the future to better manage outcomes in agricultural crop production. The three Thrusts are color coded **Thrust 1: blue**, **Thrust 2: green**, and **Thrust 3: orange** in the wiring diagram. Below, current project thumbnails are sequenced to represent how they contribute and are connected to realize the Center's overarching vision.

The IoT4Ag team unites a convergence of expertise in agronomy, agricultural engineering, agricultural economics, environmental sciences, and in the science and engineering of physical and cyber systems. The Center is structured into three Thrusts that vertically integrate fundamental knowledge and technology from different disciplines and are horizontally integrated to achieve

next generation engineered systems for agriculture: **Thrust 1–Agricultural Sensor Systems**, **Thrust 2–Communication and Energy Systems**, and **Thrust 3–Agricultural Response Systems**. The "flow" or "wiring" diagram in **Figure 4D.1** portrays the engineer's depiction of the structure and connectivity of the three Thrusts needed to enable the sense-communication-response integrated systems of the farm of the future to realize robust agricultural crop production with reduced environmental impact. The diagram shows how our projects fit together to achieve the broader center goals. The project thumbnails show how the individual projects in Year 4 contribute and are connected to realize the Center's vision.

The structure and connectivity of IoT4Ag Thrusts and the requisite convergence of disciplinary expertise are also shown (**Fig. 4D.1**). Plant and environmental scientists are exploring the biotic and abiotic variables that affect crop health and are working together with engineers to design and specify sensors that are embedded in the field, to measure these variables from above the canopy, inside the canopy, at the soil surface and below. Multi-mode sensors are being co-designed and co-created with energy and communications technologies for the agricultural use case that calls for sensor systems that require zero- or near-zero power, are low cost, can be deployed at large scale, and are biocompatible/biodegradable. Signals are transmitted at the "edge" to existing farm machinery or to ground and aerial robots that are being adopted by the farming community. Robots are being co-designed and equipped with energy and communications technologies to allow autonomous, coordinated multi-robot excursions at the scale of agricultural fields and to receive and process signals at the edge to create spatiotemporal maps of the field state by integrating data from point sensors and imaging sensors inside and above the canopy. A suite of Ag-specific backhaul technologies are investigated to transmit signals to the cloud in the characteristically remote and "unconnected" environments of agricultural fields. Multiple resolution sensor fusion techniques are being developed to unite the spatially, temporally, and compositionally heterogeneous sensor data. By leveraging artificial intelligence (AI), data from the field is being used to build digital twins of different cropping systems. Machine learning is enabling models that are data-driven, and yet constrained by the biophysics of plant physiology, the soil, weather, and management practices to "make the invisible visible" and provide "better data". These models are being used to build a human-centered decision-Ag interface, which coming full circle, allows farmers to intelligently manage their fields to ensure crop yield and resiliency in a cost-effective and sustainable manner. Integrated social science research projects in IoT4Ag aim to understand barriers to adoption and social impacts of the technology being developed.

Thrust 1 – Agricultural Sensor Systems research is in the design and manufacture of resilient, networked, intelligent sensor and robotic systems that monitor the state of plant and soil health over extended areas. Thrust 1 addresses fundamental scientific questions to uncover how the complex system of abiotic and biotic variables affects crop yield and resilience, and with this knowledge is designing technologies and systems that will be deployed with the spatial, temporal, and compositional resolution needed to capture the state of the field. Thrust 1 unites faculty research groups with expertise in plant and environmental science, sensors, robotics, and mapping of agricultural fields.

IoT4Ag Thrust 1 Breakthrough Technologies

- Multi-mode, low-cost, distributable, environmental and soil sensor technologies
- Autonomous aerial and ground-based robots

Thrust 2 – Communication and Energy Systems research is in enabling advanced approaches for powering IoT devices and robots in the field and for data communication from heterogeneous platforms of sensors, robots, and farming equipment. Thrust 2 is working to establish the knowledge and technologies specifically needed for IoT-enabled precision agriculture, including biodegradable power sources, approaches to charge and communicate with devices below the soil surface, and processing and transmitting data from systems deployed at field scale. Thrust 2 is composed of faculty with expertise in IoT sensors and robotic power and in edge and backhaul communication.

IoT4Ag Thrust 2 Breakthrough Technologies

- Energy storage and delivery technologies for field-scale operation
- Ag-specific edge and backhaul communications

Thrust 3 – Agricultural Response Systems research is to build and deploy smart response systems that are driven by AI, machine learning, and decision-based models for precision agriculture. Thrust 3 is creating techniques to manage uncertainty and fuse the spatially, temporally, and compositionally heterogeneous data from the field to collect not just more, but better data. Thrust researchers are using data from the field, public weather sources, and satellite imagery to build digital twins of row and tree crops. Models, enabled by machine learning and constrained by the biophysics of crops in agricultural fields, are being used to establish a user-friendly, decision-Ag interface for growers to intelligently manage their fields in a cost-effective manner. Thrust 3 brings together faculty groups with expertise in machine learning, AI, sensor fusion, and decision agriculture architectures and interfaces.

IoT4Ag Thrust 3 Breakthrough Technologies

- AI-driven digital twins of row and tree crops
- Human-centered decision-Ag interface for agricultural management

ORGANIZATION AND MANAGEMENT OF CONVERGENT RESEARCH ACTIVITIES: THE 3-PLANE AND THE 10-YEAR MILESTONE CHARTS

The three-plane strategic planning chart is shown in **Figure 4D.2**. We have made progress in specific areas on all three planes of the chart as detailed in the individual project reports (**Appendix VII**) and below in the description of research by Thrust. From a system perspective, we continued the development of our three testbeds (see descriptions below) and three Joint Ops (1. Integrated systems to optimize N application in row crops, 2. Integrated systems to optimize water use in tree crops, 3. Integrated systems to mitigate crop loss due to disease and pests) that focus our efforts on system integration on key challenges in agriculture.

The convergent research activities are central to the Center and integrated with other Center activities. **Figure 4D.3** depicts the IoT4Ag convergent research component roadmap, which shows the process for project definition, design, development, deployment, evaluation, and selection and for engagement of our advisory boards. The roadmap has an inner loop, which describes monthly activities that include IoT4Ag seminars, Thrust meetings, and Center-wide meetings that provide a channel for communication of research progress and barriers, an opportunity for feedback and suggestion of new ideas, and coordination of research thrust and testbed activities; as well as joint

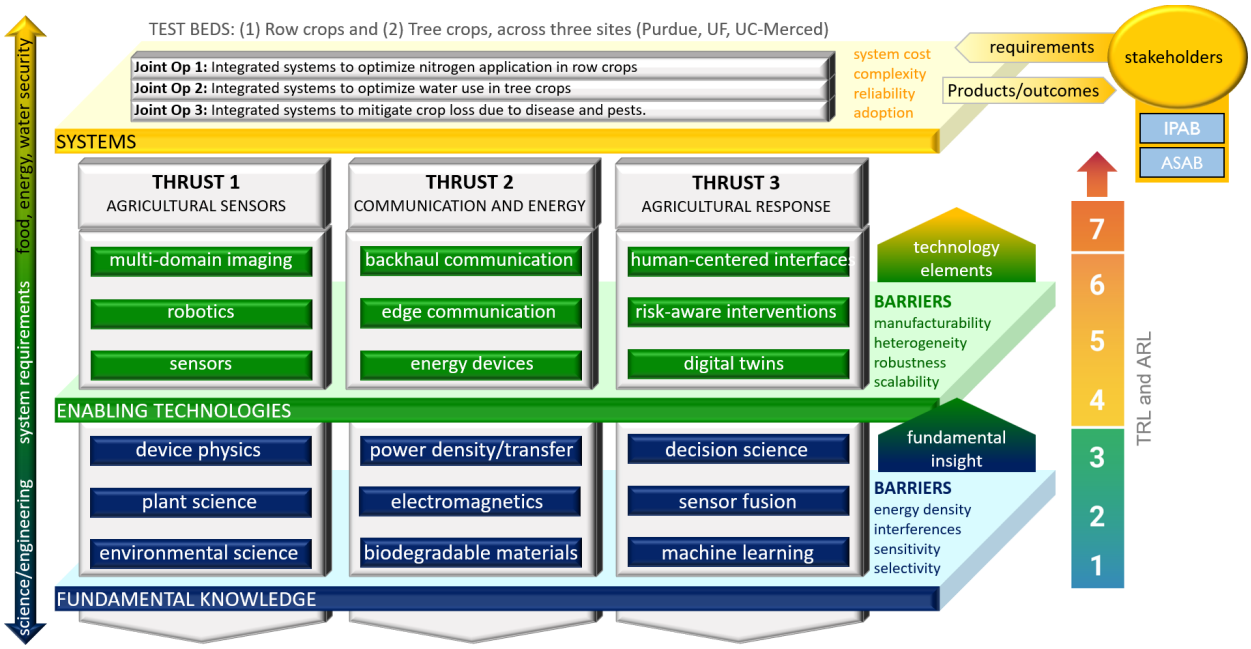


Figure 4D.2 IoT4Ag's ERC 3-plane strategic chart.

activities with our EWD, DCI, and IE pillars. This roadmap also outlines the process for project definition and design. The inner loop also shows the cadence of research projects that begins with project definition and design based on a needs assessment. This process was established in Year 2, and was used in Years 3 and 4. Continuing projects and new project proposals are evaluated and selected on an annual basis, with guidance from the SAB, IPAB, and ASAB.

The outer loop of the roadmap shows the cadence of project development, deployment, and evaluation of newly selected and continuing projects. The cadence of each project will vary depending on the specific project design and activities as appropriate to meet its goals. Deployments will bring IoT4Ag technologies to our Joint Ops designed to enable system integration of IoT4Ag technologies in our testbeds. This year, we provided feedback from the SAB, IPAB, and ASAB and executive committee to all projects via mid-year reviews to allow for projects to make course corrections prior to submissions for project renewals. Throughout the year, Testbed Office

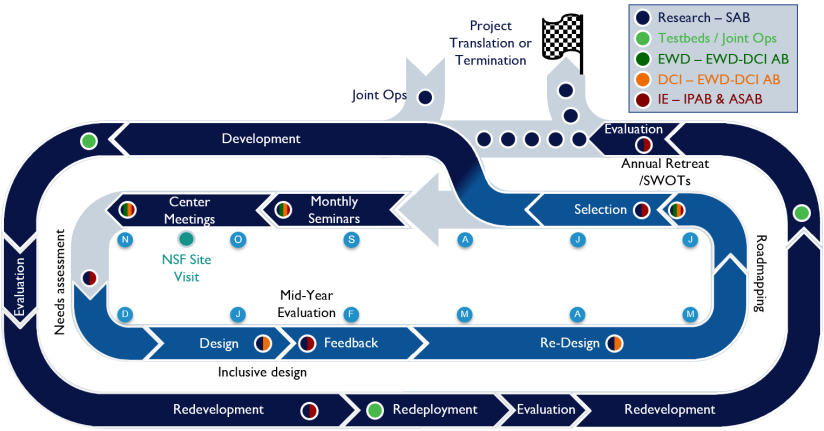


Figure 4D.3 Convergent Research Roadmap describing the annual research cadence and engagement. (Inner Loop) Iterative project definition and design with stages for early feedback before formal evaluation and selection. (Outer Loop) Iterative development and deployment of selected projects. (Top) On ramps reflect annually defined joint operations (Joint Ops) that unite technologies around integrated systems for precision farming of row and tree crops. Off ramp depicts the translation or termination of projects. SAB = scientific advisory board; IPAB = industrial practitioner advisory board; ASAB = Ag-systems advisory board. Months of the year (blue circles) and relationship to other IoT4Ag Pillars (colored circles).

Hours are held monthly to support projects as they work to plan for technology deployment and evaluation in Joint Ops and Testbeds.

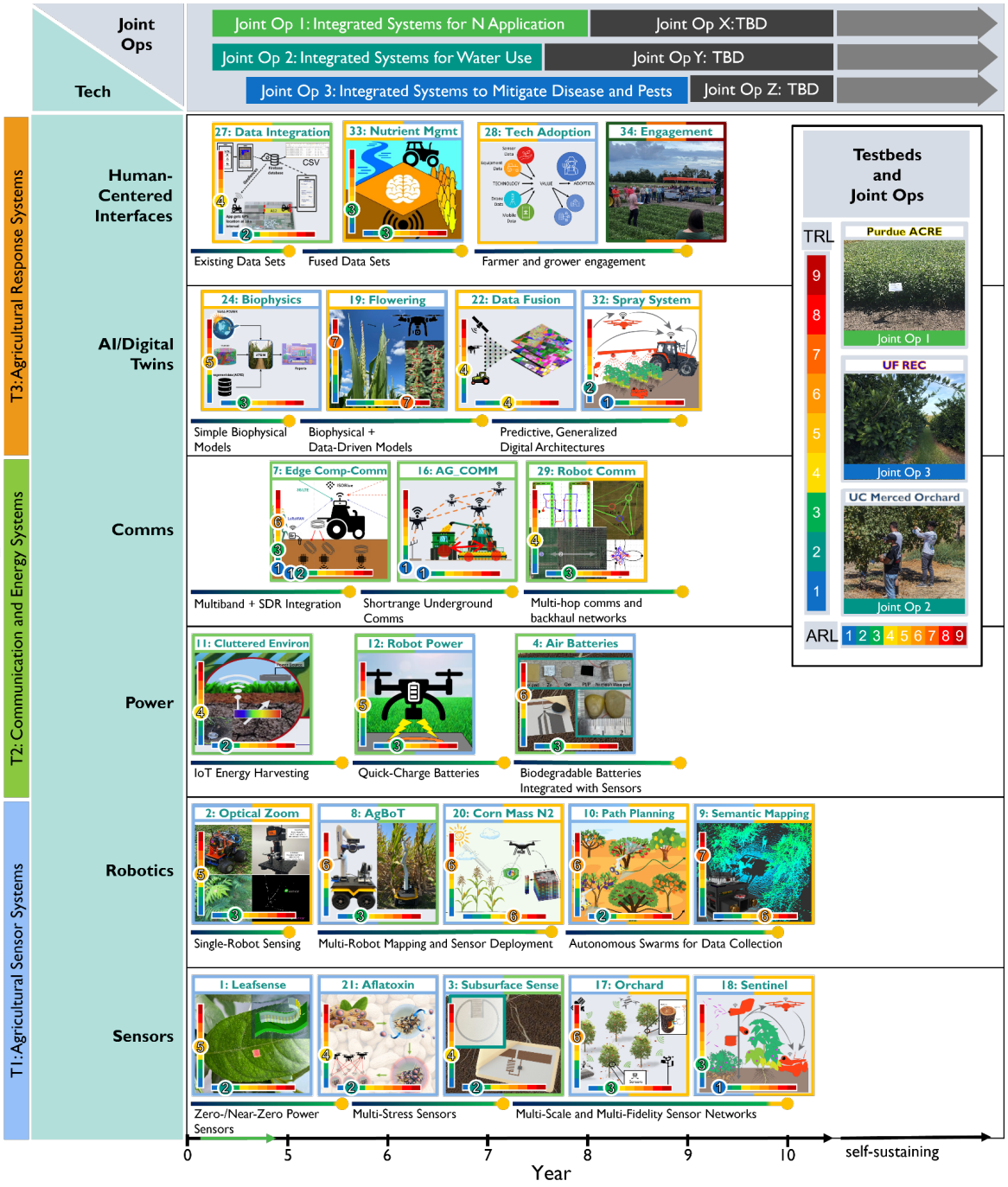


Figure 4D.4 IoT4Ag's 10-Year Milestone Chart showing short-, medium-, and long-range goals.

In Year 4, IoT4Ag convergent research continued 23 projects from Year 3 to deliver on the ERC's Center-level goal of creating integrated sensor-communication-response systems. Five projects were sunset or merged with other projects between Year 3 and Year 4 based on alignment with Center goals. While no new projects were launched going into Year 4, the scope of some existing projects was adjusted and expanded to address unmet needs in the Center. 1 new project spanning

engineering workforce development, diversity culture & inclusion, and innovation ecosystem was launched to work with and strengthen the engagement of stakeholders in IoT4Ag research.

The 10-year milestone chart in **Figure 4D.4** presents the projects and their technology readiness levels (TRLs) and adoption readiness levels (ARLs). The milestone chart depicts current projects and their work in thumbnails. The projects are positioned in the chart to show how they contribute to IoT4Ag "breakthrough technologies" and are sequenced to show their connectivity within those technologies. The box around the thumbnails is color-coded to reflect the thrusts that collaborate to carry out the project research, and a color-coded bar and number mark the TRL and ARL for each project. The social science projects intentionally and appropriately do not have TRL/ARL. For the 23 current research projects, 19 projects (83%) are collaborative across thrusts.

Thrust Milestones: Below, we summarize and provide a status of each of the Year 4 milestones.

Table 4D.1. Summary of Thrust 1 milestones for Year 4.

	Activities	Milestones	Assessment (June 2024)
Thrust 1	Design and fabricate sensors for measuring leaf moisture content. (*1*_LEAFSENSE)	Demonstrated ability to differentiate leaf wetness from relative humidity.	Field test completed in UC Merced tree crop testbed.
	Demonstrate an autonomous robot for locating and measuring colorimetric sensors in the field (*2*_OPTICAL ZOOM*)*	Successfully located and measured colorimetric sensors in both day and night conditions.	Field test completed in UC Merced tree crop testbed
	Design, fabricate and characterize wireless soil sensors. (*03*_SUBSURFACE SENSE)	Wirelessly measure soil moisture over 4 days.	Wireless soil moisture measurements were demonstrated in the Purdue ACRE testbed.
	Develop mapping and localization systems for heterogeneous robot teams, enabling UAVs to explore GPS-denied environments in orchards and forests autonomously. (*9*_SEMANTIC MAPPING)	Extended systems from 3D to 4D for persistent monitoring of environmental changes and gathering accurate, actionable information over time.	The project created photorealistic maps, estimated yields, and monitored forests and orchards over time.
	Develop a framework for accurate in-row and under-canopy localization in cornfields, create an autonomous navigation system for large-scale cornfields, advance a transformer-based approach for leaf pose estimation, and develop an algorithm to measure corn ear height using a YOLOv8 network. (08_AGBOT)	Developed the Purdue AgSLAM framework for accurate in-row and under-canopy localization in GNSS-denied environments.	Successful testing of an autonomous navigation system, transformer-based leaf pose estimation, and a corn ear height measurement algorithm with high accuracy on artificial plants.

Table 4D.2. Summary of Thrust 2 milestones for Year 4.

	Activities	Milestones	Assessment (June 2024)
Thrust 2	Design, develop, and optimize battery materials and packaging to realize biodegradable batteries. Develop plan for battery biodegradability and toxicity tests at plant testbed; begin integration of battery with subsurface sensors. (*4*_AIR BATTERIES)	Show Zn-air battery lifetimes under sensor-relevant discharge conditions exceeding three months in air and in under soil conditions in the laboratory. Demonstrate battery performance in field tests.	Large-cell (cm-scale) battery lifetimes under sensor-relevant discharge conditions as long as 240 days under soil in the laboratory and nearly one year in air in the laboratory demonstrated. Miniature 'corn cell' battery lifetimes under sensor-relevant discharge conditions of approximately 2-3 months in the laboratory. Field testing carried out at Purdue and Florida using batteries integrated with LoraWAN installations. Lifetimes in the field of up to 1.5 months under soil demonstrated.
	Design communication and signal processing algorithms for precision agriculture use cases. Implement experimental in-field communication. . (*16*_AG COMM)	Analyze low-power backhaul scenario for communications in the field. Develop new precision ag wireless channel models. Initial results on integrated sensing and communications.	Developed dual-function positioning and communications approach. Results on low-power wide area network deployment for precision ag use case. New channel modeling results.
	Develop sensor communication solutions for soil sensors. Implement hardware for in-field testing of sensor communications using available commercial systems. (*7*_EDGE COMP-COMM)	Continue experimental uses of in-field sensors. Expand signal processing results on backscatter and secure communication.	New capabilities added to Avena. Experimental capabilities expanded to multiple testbed sites. Expanded industry engagement.

Table 4D.3. Summary of Thrust 3 milestones for Year 4.

	Activities	Milestones	Assessment (June 2024)
Thrust 3	Detect water stress in plants. *(22*_DATA FUSION*, 28*_TECH ADOPTION*).*	Incorporate in-situ point-based measurements with high-resolution UAV and frequent satellite image data. Conduct a collaborative large latitudinal experiment with deliberate irrigation reduction.	Demonstrated UAV multispectral + PlanetScope satellite data can detect water stress in sorghum using NDVI and machine learning. Identified resilient breeds. UC ANR and Sorghum Board engaged.
	Assess effects of drone operations on sustainability and CO2 emissions. (22_DATA FUSION)	Life cycle analysis (LCA) of CO_2-equivalent emissions for remote sensing (manufacturing, operation) to estimate impact of drone use at scale.	LCA completed with travel to/from field sites are the dominant emission driver. Proximity and trip planning are important.
	Conduct a user interface design workshop with stakeholders. *(24*_BIOPHYSICS*)*	Develop interface for within-season nitrogen decisions; obtain feedback.	Interface is designed, feedback session with end-users to be scheduled.
	Integrate repository data (weather and soil characteristics) with APSIM and into the Avena Ecosystem as data streams. *(24*_BIOPHYSICS*, 27*_DATA INTEGRATION*)*	Back-end model accesses SSURGO data and weather from POWER.SSURGO data integrated with a public data abstraction service (PDAS). Vehicle position from LoRaWAN sensors integrated with a hardware abstraction service.	Data import functions with lat/long inputs. Validation and calibration need to be completed. Weather and soil data integrated successfully; now working on use cases of the Avena data integration. Vehicle position data integrated with a context abstraction service.
	Identify how to reduce barriers to adoption. (28_TECH ADOPTION)	Develop strategies to mitigate adoption barriers. Additional interviews regarding how farmers want to learn about technology.	Community engagement identified as a key trust-building process. More interviews needed. Trust is a key modifier for economic adoption decisions.
	Improve model predictive skill required to optimize sensor placement and impact assessments of sensor use.	SWAT model fused with machine learning.	Predictive skill for soil moisture increased from r2=0.36 to r2=0.56.
	Evaluate predictive algorithm for nitrogen management (33_NUTRIENT MANAGEMENT)	Field experiments conducted at Florida testbed.	Due to excessive rain and wind the experiment was terminated by Sept 15.

RESPONSE TO SWOT from YR4 Site Visit

Weaknesses:

- The critical aspect of **biodegradability** and safety regarding the sensors and batteries in the soil should be considered at the research's onset rather than being deferred to the end, as indicated in the Center's response. Biodegradable sensors should have a plan to move towards complete (or at least as complete as possible) degradability. Sometimes petroleum derived substrates were being used for sensors.

RESPONSE:

Biodegradability has been considered from the start in the research projects focused on field-deployable sensors and batteries. For example, in the soil sensor project (Project 3: Subsurface Sense), our sensor development efforts have focused on building devices on cellulose-based substrates, and we have been developing non-toxic Cu inks for the conductive traces. This has been the research plan and approach from the start of the project. Similarly, the leaf sensor effort (1_Leafsense) has used chitosan (a biopolymer) as the main sensor material from the start. Finally, the biodegradable battery project (4_Air Batteries) has also focused on biodegradable and non-toxic materials. In fact, we believe that our work to develop biodegradable sensors and batteries is a core technology of IoT4Ag and a key area where we will have transformational impact. We note that in some testbed trials of communication technology (i.e., the OATSMobile platform) used off-the-shelf polymer RFID tags (not sensors) to evaluate the performance of wireless communication approaches. These tags were simply used as stand-ins as the biodegradable sensors are being developed to ensure we can move forward with development and validation of communication technologies in parallel with sensor development.

- The peer-reviewed publication count seems low given the number of participants and the size of the award and when benchmarked against other ERCs.

RESPONSE:

We appreciate the importance of publications to the dissemination of IoT4Ag research and as a measure of Center productivity. The center publication record grew significantly in Year 4 (this comment was by the 2023 SVT based on data from Years 1-3). As seen in the data below, there was a large increase in IoT4Ag publications as center research has matured and we expect this growth trajectory will continue in Years 5-10.

	YR1	YR2	YR3	YR4
Peer-reviewed Technical Journals	1	5	3	23
Peer-reviewed Conf. Proceedings	4	2	11	15

To provide some context to the publication numbers for the center, we note that (1) the nature of some of the Center's agricultural research projects involve multi-year field-based measurements and analysis that take time to conduct, analyze, and publish, (2) IoT4Ag launched during the pandemic and thus the Center publication rate in the first couple of years may be slower than historical ERC averages. We enjoy working with our students and supporting them as they work to complete and publish their/Center research.

- Communication research has primarily focused on using off-the-shelf modules to augment the sensors instead of specifically innovating on the communication component. Further, the computation combined with the **communication project** has made insufficient progress leveraging the state-of-the-art computation techniques to reduce the amount of data that needs to be communicated.

RESPONSE:

Over the past year, Thrust 2 communications research has worked to enable in-field technologies that have a short transition time to support Thrust 1 and 3 research. This work has been focused on software development and development of in-field testbed capabilities. Successes include the development of the OATSMobile platform for in-field communication and computing, the design and deployment of an AVENA-based data streaming and processing pipeline that enables sensor data to be flexibly integrated with almost any communication technology and application.

Additionally, an AVENA-based pipeline enables event-based interoperability with other computing nodes in an agricultural context, allowing data transformation, aggregation, and further processing at different stages. For instance, our proposed pipeline enables data integration between machine systems via point-to-point communications, where machines with distinct sets of sensors transmit event messages (i.e., data originating from sensor readings) for further processing and aggregation by other systems (e.g., UAVs transmitting raw data samples to other in-field compute nodes without power constraints for further image processing). In the same way, our pipeline integrates developments of other Thrust 2 and Thrust 3 projects. In our study case, while RFID systems are off-the-shelf, the OATSMobile and AVENA are custom-built.

Simultaneously, we have also performed forward-looking research. Results include new results on secure communications, multi-hop communications, and sensor communications. The techniques developed are forward-looking and could impact beyond-5G systems.

Thrust 2 research is interested in edge computing and communications techniques that can reduce the amount of data that needs to be communicated. Further, Thrust 3 research is focused on identifying key in-field measures necessary for state estimation and logistics.

- The fundamental research aspects of Thrusts 2 and 3 are lacking. We encourage Center Leadership to pursue more fundamental challenges such as robust communication with sensors underneath the soil. Also, despite the strong data curation efforts, the utilization of data for decisions (e.g., related to crop yield) seems a bit limited, using mostly standard data science techniques. More recent AI/ML techniques could be explored, e.g., for understanding which data features are truly helping/augmenting the sensing/decision process, unsupervised learning for lack of labels, transformers for sequential data. The data sharing between the teams is somewhat fragmented, leading to bottlenecks in data science components and repeated experimentation.

RESPONSE:

One aspect of this work that is a fundamental paradigm shift in agriculture is to reframe existing research models and tools (specifically DSSAT and APSIM) into tools that can be used to make in-season (adaptive) crop management decisions. This requires the crop models to be parallelized in order to represent the crop growing on a farm field as a set of parallel model simulations of "pixels" representing individual plants or small plant groupings, which is

needed to represent a field containing millions of plants, tens of hydrological soil classes, and hundreds of microclimates. The individual "pixels" will be interconnected by topography, which controls water flow, spatial proximity and relative direction from one to another, which relates to the paths taken by machines through the field, and temporally varying wind directions. Simulations of this nature, which are the basic state-space model needed for a corn field digital twin, will represent an interesting challenge for the design and programming of GPU systems. This is a substantial and novel idea, which will enable IoT4Ag to use densely deployed sensing and precision ag treatment systems to operate a corn field at 100-acre scale as a control system, albeit with a huge state space, in order to optimize yield and profitability subject to constraints related to sustainability goals.

The previous will enable in-season adaptive decisions, which are the focus of Thrust 3. We are well on our way toward this even though we didn't have the opportunity, given time constraints, to present the work during this site visit. Those models need more data than most researchers, and certainly practitioners, have "handy". This is why we worked on data integration early. We are striving for plenitudinous (complete) data because, frankly, in agriculture nobody has it.

A strong complement to this is the Thrust 2+Thrust 3 integrated work on NATS and data flow so that we deal with interoperability at the event level. In agriculture, we must move beyond trying to only deal with ag data in files. Those files "arrive" too late to be of full value. Furthermore, by moving toward event level interoperability, we streamline data processes in parallel manners for both "fetched" and "streamed" data. For example, we say and everyone believes that anyone can get weather, topography, and soil data. This is only true for coders and researchers. To have it "together" in an insightful decision supporting manner is still a work in progress around the world. We are making progress on this and data sharing between teams does require a deliberate effort, which was duly noted by the site visit team. The suggestion to do this better is noted.

We will soon be able to act on information regardless of the source (whether sensor, observation, public data repository, historical records, etc.). The video by Balmos (*https://youtu.be/AIRFgFjI4-Y*) and two posters presented at the site visit cover these topics.

Looking forward to Years 6-10 (see below), all thrusts will contain a mix of projects that investigate fundamental and applied aspects of sensors, power and communication, and AI-driven models for agriculture.

- There can be more interactions between the different Thrusts when deploying and studying some of the novel sensors (e.g., depth of install for below ground sensors, readout approaches (wave propagation/depth, etc.).

RESPONSE:

We agree and increased interactions have occurred as technologies have matured, and more interactions will occur in the coming years. For example, in 2023 3_Subsurface Sense, successfully field-tested biodegradable soil moisture sensors at Purdue's ACRE facility using inductive antennas. The short-range inductive antennas were chosen to enable rapid field testing of the biodegradable sensors, but we are working to replace them with a longer-range dipole antenna and RFID based readout. Synergistically, in 2023, 16_AG COMM, explored communications with buried RFID devices including the field testing of commercially available RFID devices buried at different soil depths. As part of the field testing, an RFID

reader platform was deployed on ACRE agricultural equipment and AVENA was upgraded to support RFID interrogation. The techniques and technologies developed in 16_AgComm will be used to interrogate future versions of the subsurface sensors, enabling the sensors to operate at much longer ranges and deeper soil depths.

Threats:

- We suggest that the ERC faculty members provide sufficient support to students for publishing research. The SVT understands that cross-disciplinary work can sometimes be challenging to publish, as it can often not be deep enough in the fields it is touching on. Prioritizing publications will help showcase the advancements and goals of the Center.

RESPONSE:

As described above (in Threats), we appreciate the importance of publications to the dissemination of IoT4Ag research and as a measure of Center productivity. We are also happy to support our students in publishing their research.

Middle-Band Requirements:

- The board remains underutilized despite the remarkable expertise and experience of the members. The Center could engage more with the SAB. This board has indicated that they would be open to quarterly meetings and increased engagement with projects, Center leadership, and students, **beyond the Annual Retreats.**

RESPONSE:

We currently engage the SAB through multiple routes, including: (1) the annual retreat, (2) the annual SAB SWOT analysis, (3) SAB review of project proposals, and (4) the opportunity for SAB members to serve as project liaisons. To increase interaction between the SAB and center leadership, Dan Schmoldt, was appointed as chair of the SAB in Year 4. Dan communicates with the IoT4Ag research directors (Kevin Turner and Jim Krogmeier) on a regular (e.g. bi-monthly) basis to ensure frequent communication between the SAB and the Center. Dan and the IoT4Ag research directors are collaboratively working to increase the engagement of the SAB.

- In general, for most of the developed sensors, additional focus should be placed on long-term performance of the devices and understanding how drift impacts calibration and accuracy over time

RESPONSE:

We agree that it is important to assess all aspects of sensor performance, including long-term performance. Most sensors being developed in Thrust 1 are designed to last one growing season (6-10 months) and we are actively working to understand and control sensor calibration and accuracy over this device's lifetime. In addition to understanding and improving sensor performance, we are also investigating opportunities to use the large number of deployed sensors and data-science approaches (Thrust 3) to realize sensor networks that can tolerate imperfect sensors.

- Some of the existing work can also use better explanation. e.g., actual drones used in agriculture may be much bigger and heavier than the small one demonstrated. It's unclear

whether AABs would be able to power them in a practical and deployable system. The benchmark for lithium-ion batteries seems low as the standard values is about 250 Wh/kg but may hail from the small weights they are using. It's unclear why a new ground platform OATSMobile is being created, instead of building upon the robot platform last year. If there's any particular reason, it should be explained. That platform seems very big; and thus its practical deployment may be limited. Also, more explanation is needed on how well the air batteries can meet the needs of various gateways in power and duration, and how well the integrated communication system can meet the needs in data rate, distance, loss, lifetime, etc.

RESPONSE:

IoT4Ag will open new uses of drones in agriculture. While typical agricultural drones, for applications such as field spraying, are large, there is a need for drones to do crop inspection and sensor interrogation, especially below the canopy. Drones for data collection and transmission can be small and lower cost.

When shrinking the size of drones, a challenge is that the packaging overhead of batteries (especially Li-based batteries) increases. This leads to reduced energy density and is a reason why air batteries have become attractive alternatives. We do not anticipate that air batteries will completely replace Li-ion batteries. However, we (along with the Industry Practitioner Advisory Board) do believe that there may be applications where extended flight duration of small-scale drones is important; and for those applications, air batteries are an attractive alternative.

With regard to powering sensors for operation and data communication, air batteries are of interest for a different reason. In such applications, which are typically sensor-adjacent, the use of environmentally benign materials such as biocompatible metals, hydrogels, and carbon-impregnated paper to form the batteries is of great importance. We believe the use of Li-ion batteries in this application class would have the potential for significantly more negative environmental impact than air batteries.

In terms of battery performance, we have demonstrated that drone flight air batteries can simultaneously obtain energy and power densities greater than 320 Wh/kg and 500 W/kg, respectively, exceeding the drone flight requirements. We have also demonstrated that the sensor air batteries can meet the typical electrochemical sensor power consumption requirements of approximately 30 μW over months-long timescales, with the ability to surge to the tens of mW-level power capability, which is more than adequate for active transmission of data from subsurface sensors.

The OATSMobile is based on a small commercial spray platform and while it is indeed much larger than the robot platform used at ACRE it is a much better platform than the robot, which is still experimental itself. In IoT4Ag we are attempting to bring many technologies (sensors, comms and networking, decision systems, and actuation) from low to high TRL levels in only a few years. One of the main reasons to use a spray platform rather than an experimental robot is the need to test new sensors and communications at field scale (i.e., over tens to hundreds of acres) to investigate performance with sufficient statistical power. To cover ten acres in a few hours would require on the order of ten small robots rather than one small spray platform. Note that commercial farm sprayers are much larger than OATSMobile (at least 5 times larger). In addition, it should be noted that the OATSMobile platform has sufficient power to run all the sensors, communications, and computing needed to support testbed operations at scale, and

it has room and climate control needed to allow experimental and not-yet field hardened equipment to be tested. Finally, in order to provide a realistic economic pathway for IoT4Ag technologies to progress from the lab, to the field, and on to commercial use, it is important that these technologies be integrated with existing commercial systems.

- The TRL system needs to be refined over the coming year, including developing a mechanism to train and educate the participants on invention processes and technology development assessments. Additional data should be tracked over the coming years, such as demographics of the contributors to the research project/invention disclosure, issued licenses, and generated revenue.

RESPONSE:

In response to this feedback, we refined our TRL evaluation process since the last site visit. Specifically, we: (1) Had a center-level meeting focused on educating the IoT4Ag team about evaluating TRL scale in the context of IoT4Ag technologies (see table below for TRL scale). (2) Established a process by which adoption readiness level (ARL) is also assessed for each project via an IoT4Ag specific scale (see table below for ARL scale). (3) Developed a system to define/report the TRL of projects containing technologies with multiple TRLs. (4) Established a process in which TRL and ARL are explicitly reviewed in the annual project review cycle and corrected if needed. This included asking IPAB and SAB reviewers, as well as the Executive Committee, if they agreed with the ARL/TRL assessment for each project.

TRL is a well-established concept and is relevant, but we believe that for tracking the progress of IoT4Ag technologies to practice we need to introduce an ARL assessment (Note: federal agencies such as the Department of Energy have also recently started using an ARL). We created the IoT4Ag specific Adoption Readiness Level scale below to help the Center and stakeholders better assess the progress of our technologies.

IoT4Ag Technology Readiness Level (TRL) Scale

Level 1	Basic principles of technology observed and reported
Level 2	Technology concept and/or application formulated
Level 3	Proof of concept / critical function demonstrated via experiments and/or modeling
Level 4	Validation and demonstration of technology in benchtop laboratory experiments
Level 5	Technology validation in IoT4Ag-related field or testbed
Level 6	Technology integrated into a system and validated in a testbed
Level 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment
Level 8	Actual system completed and qualified through test and demonstration

Level 9	Actual system operated over the full range of expected conditions

IoT4Ag Adoption Readiness Level (ARL) Scale

Level 1	Conceived by the IoT4Ag project team
Level 2	Used by the IoT4Ag project team that conceived it
Level 3	Used by another IoT4Ag researcher (e.g., used in a testbed or another IoT4Ag project)
Level 4	Used by one organization involved with, but not funded by IoT4Ag (e.g., IPAB, ASAB member)
Level 5	Used by multiple organizations involved with, but not funded by IoT4Ag
Level 6	Used by one organization that has no involvement with IoT4Ag (e.g. another non-IoT4Ag university research team / company)
Level 7	Used by multiple organizations that have no involvement with IoT4Ag
Level 8	Used by one end-user who has nothing to do with IoT4Ag (e.g., farmer or producer)
Level 9	Used by multiple end-users who have nothing to do with IoT4Ag

- It would be useful to know what barriers exist for adoption of technology (e.g., cost metrics and social factors). Social economic considerations were mentioned but not elaborated about.

RESPONSE:

IoT4Ag is driven by the agricultural-specific use case of IoT technologies and systems, i.e., scale, environment, and socioeconomics.

IoT4Ag is working to take down **technological barriers**, by constraining technology and system definition, design, development, and deployment to meet the scale, environment, and cost of agricultural farming, e.g., by upfront specifications for materials, manufacturing processes, and device designs for sensors and their batteries to be low cost, biodegradable, and deployable using existing farming infrastructure and practices; by developing AI-driven digital twins of cropping systems, building models to fuse spatially, temporally, and compositionally heterogeneous data inherent to the scale and environment of agriculture, and an Ag-decision interface that is human centered.

IoT4Ag is also working to remove **barriers to** technology and system **adoption**. Activities across all four foundational components (EWD, DCI, IE, and Research) all contribute. For example:

- *Barrier - Cost of Technology and Systems*: IoT4Ag is creating technologies and systems to be affordable for agricultural farming, which has a distinctly different cost structure, use cycles (i.e., seasonal), and ramifications than IoT technologies for health, home, manufacturing, transportation etc.
- *Barrier - Deployment Consistent with Existing Farming Practices*: its is not just the cost of farming infrastructure, but IoT4Ag is working to create technologies consistent with current agricultural practices; by learning from IPAB, ASAB, and SAB members and farmers; and to engage community colleges, ag organizations (e.g., 4-H, MANNRS), and agricultural professionals in workforce development and diversity & culture of inclusion IoT4Ag E^3 ENABLE Professional Advancement activities/events to educate farmers on the use of IoT technologies and systems.
- *Barrier - Trusted Relationships*: IoT4Ag is working to build trusted relationships and social networks with extension agents, crop consultants, early adopters/leaders etc through Ag Professional Engagement activities and with IPAB and ASAB members (e.g., Latino Farmers, SEEN) and regional organizations (e.g., PA Ag collaborative). Some of these activities are part of Project 34_ENGAGEMENT.

As we evaluate technologies in the field, it is also now timely to engage policy makers (e.g., state departments of agriculture) in a dialogue about how new IoT4Ag technologies can lead to improved policy making, seeking to reduce water use and contamination.

RESEARCH PROGRAM BY THRUST

IoT4Ag Year 4 projects were selected based on their ability to deliver on the Center mission "to create and translate to practice Internet of Things (IoT) technologies for precision agriculture". The projects are collaborative, exploiting IoT4Ag's convergence of disciplinary expertise, uniting IoT4Ag institutions and Thrusts/testbeds (listed below), and span fundamental knowledge, enabling technologies, and systems. Most (21 of 24) of the projects are collaborative with faculty and students from multiple disciplines, 21 of 24 projects span research Thrusts, and 16 of 24 include multi-institutional teams.

From Year 4 to Year 5, two projects were concluded and ideas from three new project proposals were incorporated into existing projects. Thus, in Year 5 there are 22 projects running. While this report focuses on research covered by the 24 projects that ran in Year 4, the 22 projects in Year 5 set the stage for our plans for years 6-10 described later in this section.

Note: Accomplishments within each Thrust are highlighted by project; project names are in italics; detailed descriptions and accomplishments for each project are in Appendix V. While many projects span Thrusts, accomplishments are reported for each project under the primary Thrust for the project.

Thrust 1 – Agricultural Sensor Systems

Thrust 1			
Name	**Role**	**Department**	**Institution**
Arratia, Paulo	Faculty	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Cappelleri, David	Faculty	Mechanical Engineering	Purdue University
Carpin, Stefano	Faculty	Computer Science and Engineering	University of California, Merced
Crawford, Melba	Faculty	Civil Engineering	Purdue University
Ehsani, Reza	Thrust Co-Leader	Mechanical Engineering	University of California, Merced
Eisenstadt, Bill	Faculty	Electrical and Computer Engineering	University of Florida
Kagan, Cherie	Faculty	Electrical and Systems Engineering	University of Pennsylvania
Koppal, Sanjeev	Faculty	Electrical and Computer Engineering	University of Florida
Kumar, Vijay	Faculty	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Messina, Carlos (Charlie)	Faculty	Horticultural Sciences	University of Florida
Olsson, Roy (Troy)	Thrust Co-Leader	Electrical and Systems Engineering	University of Pennsylvania
Quinn, Daniel (Dan)	Faculty	Agriculture and Natural Resources	Purdue University
Sharma, Vivek	Faculty	Agricultural and Biological Engineering	University of Florida
Small, Ian	Faculty	Plant Pathology	University of Florida

Sumerlin, Brent	Faculty	Chemistry	University of Florida
Turner, Kevin T.	Faculty	Mechanical Engineering and Applied Mechanics	University of Pennsylvania
Vyn, Tony J.	Faculty	Agronomy	Purdue University

***Year 4 Accomplishments**:* Thrust 1 is designing and manufacturing resilient, networked, intelligent sensor systems to instrument fields and orchards with commercial-off-the-shelf (COTS) and emerging, research sensor technologies. These sensors are probed by optical detectors and RF receivers mounted on existing farm infrastructure and machinery and IoT4Ag ground and aerial robotic systems deployed in fields and orchards. These systems are designed to meet the application specific needs of operating in agricultural fields to monitor plant and soil health at scale. Thrust 1 is addressing fundamental scientific questions of how abiotic and biotic variables affect crop yield and resilience, and the practical implementation of actuators to execute responses from Thrust 3 in the Joint Ops at IoT4Ag testbeds (described below).

Project 1_LEAFSENSE is creating colorimetric sensors based on optical metasurfaces that exhibit high quality factor (Q) resonances in the visible and NIR with adaptive polymers that respond to relevant environmental conditions. These sensors are attached to leaves and can passively and remotely sense leaf properties such as moisture. In Years 1-3, we developed a scalable and sustainable nanomanufacturing platform for fabrication of optical metasurfaces via nanoimprinting of low-cost aqueous TiO_2 nanocrystal (NC) inks. We realized a single-step method of achieving high Q resonances in the visible and NIR by tailoring residual layer thicknesses to create optical metasurfaces with waveguides. We also fabricated and tested biodegradable, flexible and adhesive substrates with chitosan and cellulose biopolymers for leaf compatibility. In Year 4 we deployed moisture-responsive colorimetric sensors on citrus plants by optimizing metasurface fabrication on the leaf-compatible substrates. Leaf level tests of sensors at UF and UC Merced testbeds were used to measure leaf wetness and determine requirements for interrogation of sensors on the leaf in the field. Sensor detectability was improved through (i) increasing Q, by coupling a waveguide layer to patterned pillar structures, (ii) increasing modulation up to 55%, by combining high aspect ratio structures with high refractive index NC materials (**Fig. 4D.5a,b**), and (iii)

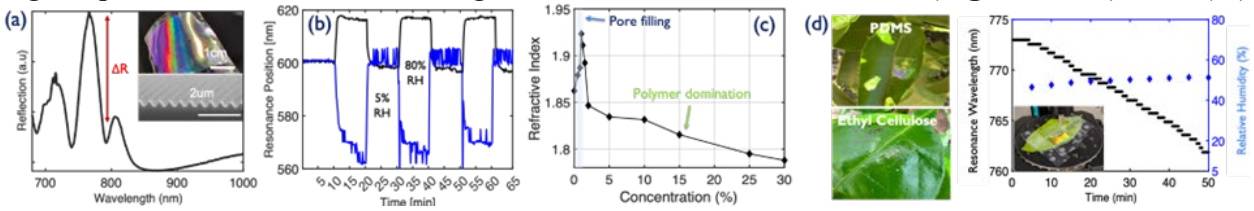


Figure 4D.5 Leaf sensor engineering: (a) Reflectance spectra of high-aspect ratio/high-index NC-based optical metasurfaces on flexible substrates, (b) RH-dependent resonance of Chitosan-TiO_2 NC composite metasurface fabricated on glass (black) and Chitosan (blue) for high sensitivity sensors, (c) Refractive index of chitosan-TiO_2 NC composites, showing enhanced refractive indices at low concentration and enabling NC metasurfaces with high FOM via improvements in S and Q, and (d) substrate adhesion to citrus leaves, and tracking of leaf wetness showing an expected spectral shift relative to a nearly constant RH environment.

significantly increasing sensitivity (S), up to 300%, by exploiting the colloidal nature of our inks and incorporating controlled amounts of adaptive polymer into the TiO_2 NC inks. We discovered that polymer incorporation also allows the refractive index of our devices to be enhanced by ~ 8% (**Fig. 4D.5c**). This approach allows us to create high figure-of-merit (FOM) tunable metasurfaces on responsive substrates, not achievable with conventional bulk processes. Sensor architectures that distinguish and measure leaf wetness from environmental relative humidity (RH) were

validated using PDMS and ethyl cellulose substrates. Sensors are designed to respond to leaf wetness selectively over changes in local leaf humidity by using architectural degrees of freedom such as the sensor orientation. This is achieved by forming a cavity at the leaf surface that contains the metasurface and adaptive polymer backed by an impermeable substrate such that any moisture changes are solely attributed to leaf wetness (**Fig. 4D.5d**).

2_OPTICAL ZOOM, a cross-thrust (1 & 3) project, is developing an autonomous robotic imaging platform (**Fig. 4D.6a**) that can localize and measure Project 1_LEAFSENSE colorimetric sensors deployed in the field. This involves a system integration of (1) a ground-vehicle capable of traversing agricultural fields, (2) a visual servoing controller and algorithms to localize and maneuver towards plants with colorimetric sensors, (3) a colorimetric sensor segmenter to detect and measure the sensor's spectral response with RGB and Hyperspectral cameras, respectively. In Year 4, a YOLOv7 model was successfully trained to localize the sensors in various lighting conditions (**Fig. 4D.6b-c**) and a homography algorithm was demonstrated to map the location of the sensor and position the robot for hyperspectral image acquisition. Indoor and outdoor hyperspectral imaging of various colorimetric sensors identified two wavelength regimes for

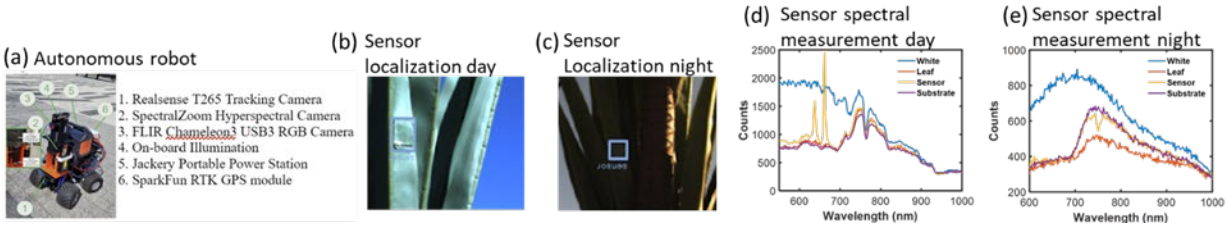


Figure 4D.6 (a) Autonomous robotic imaging platform for finding and measuring colorimetric leaf sensors. YOLOv7 sensor localization under (b) outdoor bright and (c) outdoor low light conditions. Spectral measurements showing the colorimetric sensor response (d) in the visible for daytime operations where the sensor response appears at as a peak at a specific wavelength and (e) in the near-IR for nighttime sensing with artificial light where the sensor wavelength appears as a dip at a specific wavelength.

optimal sensor operation: Shorter visible wavelengths (~550-650nm) in which leaf reflectance is low and the sensor resonance appears as a peak, ideal for outdoor measurements using sunlight (**Fig. 4D.6d**), and longer near-IR wavelengths (~750-850nm) in which leaf reflectance is highest and sensor resonance appears as a dip (**Fig. 4D.6e**), which is ideal for indoor and nighttime measurements using artificial halogen light illumination.

21_AFLATOXIN, a cross-thrust (1 & 3) project, uses molecularly imprinted polymer (MIP) networks which will be immobilized on the metasurface developed in the 1_LEAFSENSE. MIPs absorb aflatoxin, altering their refractive index. This change in refractive index can be used to realize optical sensors with sensitivity to aflatoxin. MIPs are polymer matrices that have complementary sites to the size, shape, and spatial arrangement of a molecular template introduced during polymerization. In Year 4, the project explored different monomers, crosslinkers, monomer to crosslinker ratio, and polymerization time and the impact this has on the particle morphology as well as the efficacy of the MIP system. As a complementary approach, the project also explored the use of aptamers for aflatoxin detection. Aptamers are short, single-stranded DNA or RNA molecules that can bind to specific target molecules with high affinity and specificity. This provides a visual detection method through color change upon binding of aflatoxin. Both of these approaches (MIP and Aptamers) are useful for real-time field-based monitoring. To prevent planting of peanut seeds at high risk from aflatoxin a machine-learning model was demonstrated based on hyperspectral images that can differentiate healthy from abnormal peanut seeds with

black mold, white mold, or yellow spores. Abnormal seeds are one of the risk factors that can lead to aflatoxin contamination.

3_SUBSURFACE SENSE a cross-thrust (1 & 2) project is creating largely biodegradable RF sensors that operate below the soil surface. To realize such sensor systems, sensor components such as biodegradable CNF-cardstock substrates, highly conductive, screen printable, biodegradable Cu nanoparticle inks for trace routing, biodegradable wax packaging, and different types of sensors including capacitive (moisture, nitrate) and electrochemical (phosphate, nitrate) are being developed. In Year 4 we tested multiple biodegradable wireless soil moisture sensors (**Fig. 4D.7a**) in the field at the Purdue ARCE testbed. The sensors were successfully measured for 4 days in the soil without failure and operated through a rainfall event. We also explored packaging of these sensors using biodegradable bees wax (**Fig. 4D.7b**) and established a test setup for measuring sensor lifetime. While the initial sensors were inductively coupled with a range of about 5 cm, a technique to extend the range based on pairing the sensors with a tiny acoustic resonator

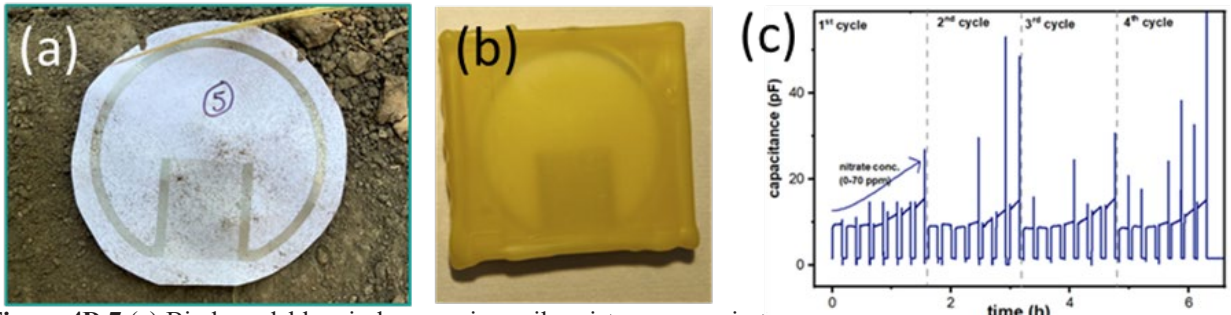


Figure 4D.7 (a) Biodegradable wireless passive soil moisture sensor in the ARCE testbed at Purdue. (b) Packaging of the sensor in (a) in beeswax. (c) Measurements of a capacitive nitrate sensor formed using a nanoparticle ink patterned on a CNF/cardstock biodegradable substrate and an ion selective membrane. The sensor is measured from 0-70 ppm nitrate in aqueous solution showing a ~2x increase in capacitance.

was explored and the resonator's frequency could be passively measured at ranges of 3 m. The passive capacitive sensor platform (screen printed nanoparticle inks patterned on a biodegradable CNF cardstock substrate) was augmented with an ion-selective membrane to realize a nitrate sensor. The sensor showed a ~2x change in capacitance with nitrate concentration from 0-70 ppm and was demonstrated over several cycles (**Fig. 4D.7c**). All of our prior sensor demonstrations utilized Ag nanoparticle inks. In Year 4, we successfully realized a soil moisture sensor based on Cu nanoparticle inks which are much more acceptable to biodegrade into the soil. Finally, the active biodegradable phosphate sensors were tested using water samples sourced from tile drains in Indiana and irrigation canals and ditches in South Florida.

20_CORN MASS N2, a cross-thrust (1 & 3) project, in Years 1-3, has been collecting data from integrated sensors on UAV platforms, combined with ground reference sampling of corn phenology, biomass, and nitrogen (N) uptake, to develop end-of-season predictive models for development-stage specific biomass and N efficiency predictions. During the 2023 growing season (Year 4), hyperspectral and LiDAR remote sensing data were acquired approximately weekly by a UAV over the Purdue testbed, where N fertilizer was applied at rates of 0, 60, 120, and 180 lbs N/acre at the beginning of the growing season in a randomized complete plot design with a single variety. The long short-term (LSTM) stacked neural network model developed in previous years based on remote sensing, environmental, and management practice data was extended to include a mid-season temporal attention mechanism to align with crop phenology, multi-modality architectures with late-stage fusion, and plant genetics. It was validated in both the Purdue testbed and in a plant breeding experiment that is part of the Genomes-to-Fields initiative, a public-private

partnership to support translation of maize genomic information for the benefit of growers, consumers, and society. Model generalization for yield prediction from multiple time periods in the growing season was successfully demonstrated via transfer learning, reducing requirements for reference data and training time for models.

Project 8_AGBOT, a cross-thrust (1 & 2) project aims to design and test an autonomous UGV that can monitor and sample crops at optimal locations and times during the growing season (**Fig. 4D.8**). The UGV will collect whole-leaf samples from different heights to analyze crop stress and will be equipped with sensors to gather additional data like crop diameter and ear height. Drone

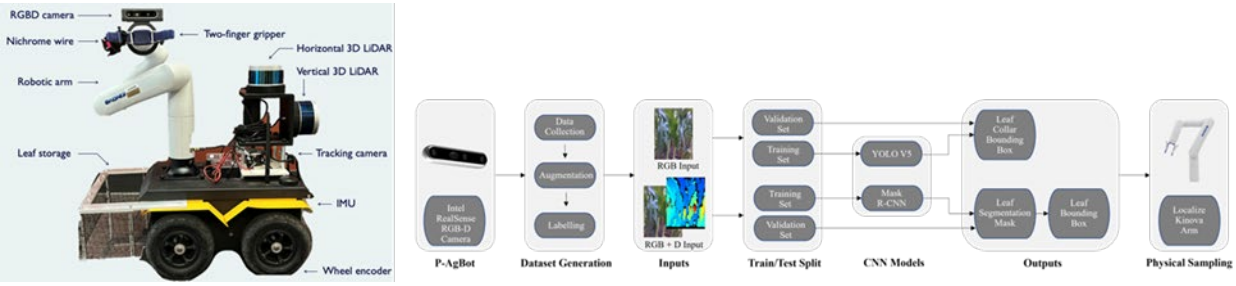


Figure 4D.8 (a) Updated version of P-AgBot physical sampling robot. (b) Deep learning-based leaf detection for robotic physical sampling.

imagery will complement UGV sampling by providing above-canopy views for stress detection. This system aims to enable timely and efficient crop scouting, which is currently labor-intensive and often inaccurate. It can also enable targeted interventions in the field. The UGV addresses the limitations of existing robotic platforms, which are either too large or too heavy for regular use without risking soil compaction. The project achieved several key accomplishments over the last four years. In Years 1 and 2, a UGV platform capable of navigating in-row and under the corn canopy for physical sampling was designed and prototyped alongside the development of corn stalk height and radius estimation algorithms. In Year 3, the sensor suite was updated, and the P-AgSLAM algorithm, which uses LiDAR for simultaneous localization and mapping in corn fields, was developed. Additionally, deep learning-based leaf detection methods using Mask R-CNN and YOLOv5 were introduced. Key accomplishments in Year 4 include the improvement of P-AgSLAM, a specialized Simultaneous Localization, and Mapping (SLAM) framework for accurate in-row and under-canopy navigation in cornfields. This system reduces odometry drift and estimates robot trajectories in cluttered, GPS-denied environments using a LiDAR-based feature extractor and a GPS-integrated robot state estimator. The project also advanced an autonomous navigation system for large-scale cornfields, which includes in-row navigation, path recovery, and crop counting, validated in simulations and field tests. A transformer-based leaf pose estimation method was developed to overcome the challenges of detecting overlapping corn leaves in outdoor lighting conditions, improving precision for physical sampling. Lastly, an algorithm for corn ear height measurements was created using YOLOv8, achieving high accuracy with minimal errors in detecting ear attachment points on artificial corn plants.

Project 17_ORCHARD aims to develop technology for more efficient water stress monitoring, specifically in predicting tree-specific stem water potential. Developing technology for fast and cost-effective detection of tree-specific water stress can help growers improve the precision of irrigation schedules and simplify the application of techniques such as deficit irrigation to use less water. The project successfully developed a model-based water stress detection system for pistachio and almond trees using easy-to-collect and cost-effective spatial data and an AI model. Also, the project developed a cost-effective sensor to measure leaf water content. These

innovations aim to help growers improve water use efficiency and irrigation practices, such as deficit irrigation. In Years 1-3, the test sites were equipped with different sensors and a communication system, and a significant amount of data was collected. The efforts to build out this site with sensors and communication infrastructure now allow this orchard to function as a testbed. In Year 4, in addition to collecting more field data, different machine learning algorithms were applied to UAV-based aerial images, weather, and sensor data to predict stem water potential (SWP) in pistachio and almond trees, achieving up to 92% accuracy with Random Forest models. Key features influencing predictions were weather, canopy temperature, and vegetation indices (OSAVI for pistachios, NDVI for almonds). Additionally, two versions of a water stress sensor clip (WSSC), based on off-the-shelf components, were developed to measure leaf water content. One of these can estimate leaf water content without removing the leaf from the tree (**Fig. 4D.9**). Initial testing suggests the sensor could be a faster, cost-effective alternative to traditional pressure chambers for irrigation scheduling.



Figure 4D.9 Newly developed WSSC sensor.

9_SEMANTIC MAPPING is working to develop a system capable of surveying large-scale, challenging agricultural environments and gathering high-quality data to extract actionable information. The project uses autonomous aerial and ground robots combined with advanced metric-semantic mapping algorithms to enable more accurate and efficient agricultural surveying. By open-sourcing UAV navigation and mapping code, the project lowered the barrier of entry for users to deploy autonomous robots in agricultural fields. In Years 1 and 2, the hardware system and data analysis methods aimed at facilitating the collection, processing, and extraction of actionable information from agricultural data were developed. In Year 3, the team created TreeScope, the first semantically segmented LiDAR dataset collected with robotic systems in agriculture. It provides valuable data for tree counting, mapping, and diameter estimation. In Year 4, significant accomplishments were achieved in developing advanced robotic systems and mapping technologies for agricultural environments. A real-time decentralized metric-semantic SLAM approach was developed, enabling heterogeneous robot teams to autonomously explore 3D spaces like orchards and forests without relying on GPS and to collaboratively build detailed maps for different tasks such as yield estimation or tree trunk size variability mapping (**Fig. 4D.10**).



Figure 4D.10 Autonomous UAV System and Collaborative Metric-Semantic Mapping of Forests.

Also, advances in monocular event-based visual-inertial odometry (VIO) were made by devising an optimal procedure to convert event camera data into multi-channel video, enhancing navigation for small flying platforms under harsh lighting conditions. Techniques were developed to process multi-sensor data, including LiDAR and cameras, to build accurate photorealistic maps of trees and foliage, progressing toward creating a "digital twin" of a farm for detailed crop monitoring and anomaly detection. A 4D metric-semantic mapping approach was established to monitor

orchard vegetation over time, accurately extracting fruit sizes, colors, and tree trunk diameters for yield estimation and identifying spatial patterns and anomalies (**Fig. 4D.11**). Lastly, an information-theoretic approach using Neural Radiance Fields (NeRFs) for active perception was developed to optimize autonomous exploration by maximizing mutual information between past and future images, demonstrated in both simulations and real-world experiments.

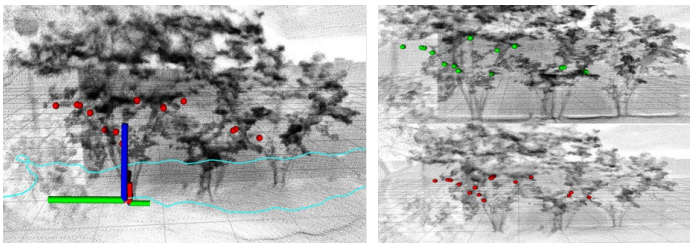


Figure 4D.11 4D metric-semantic mapping of orchards.

10_PATH_PLANNING, aims to develop optimization algorithms for single and multi-robot systems to efficiently collect data in farm environments, focusing on motion planning under environmental constraints. The goal is to design control policies for sensing robots that minimize uncertainty while considering sensor limitations and energy constraints in dynamic, canopy-covered orchards. The project's impact includes enabling precise, large-scale, cost-effective data collection from orchards using multiple robots. Key accomplishments of the project include the development of energy-aware planning algorithms using stochastic orienteering and Monte Carlo Tree Search (MCTS) for robots, with a novel enhancement through a graph neural network (GNN) to reduce planning time by predicting path quality and energy constraint violations. Additionally, the integration of a thermal camera and temperature sensor into an autonomous Husky robot has enabled large-scale data collection to estimate stem water potential in perennial crops, with ongoing cross-validation of robot and manual data showing promising scalability (**Fig. 4D.12**). During Years 1-3, the project focused on developing the needed path planning algorithm and incorporating it into robotic platforms operating in orchards and integrating with a self-developed autonomous navigation stack tailored for agricultural environments. In addition, a system to carry the sensors was developed to accommodate the collection of data from trees. In Year 4, the system was deployed at the UC Merced test site, and weekly field experiments in pistachio and almond orchards were conducted as part of efforts to collect data needed to predict trees' water stress levels and optimize water use. The objective was to determine if autonomous robots can scale the collection of temperature differentials between leaves and ambient temperature to estimate stem water potential. Initial results show that automated data collection matches manual methods, supporting the use of robotics for this task.



Figure 4D.12 Husky robot collected leaf temperature.

Thrust 2 – Communication and Energy Systems

Thrust 2			
Name	**Role**	**Department**	**Institution**
Allen, Mark G.	Thrust Co-Leader	Electrical and Systems Engineering	University of Pennsylvania
Arnold, David	Faculty	Electrical and Computer Engineering	University of Florida
Bidstrup-Allen,	Faculty	Chemical and Biomolecular	University of Pennsylvania

Sue Ann		Engineering	
Eisenstadt, William	Faculty	Electrical and Computer Engineering	University of Florida
Krogmeier, James (Jim)	Faculty	Electrical and Computer Engineering	Purdue University
Love, David J.	Thrust Co-Leader	Electrical and Computing Engineering	Purdue University
Olsson, Roy (Troy)	Faculty	Electrical and Systems Engineering	University of Pennsylvania
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Year 4 Accomplishments*:* The IoT4Ag vision for precision agriculture will require significant advances in energy storage, energy transfer, communications, and computing. In contrast to other areas of engineering, precision agriculture will occur in rural areas, where many of the energy, communication, and computing advances of the last few decades have had minimal impact. Future precision agriculture systems will be data intensive with a reliance on large numbers of sensors, robotics and aerial platforms, and communication with cloud and control systems located far from the field. The large number of devices in the field of the future must rely on new energy sources ranging from biodegradable batteries supplying energy to ultra-low-power, field deployable biodegradable sensors; to new approaches to electrochemical energy storage capabilities that enable extended operational duration of both ground vehicles and aerial drones. Further, approaches to energy distribution across distances and with energy transfer rates exceeding typical capabilities must be investigated.

In Thrust 2, we are researching solutions to energy and communication challenges that must be overcome to support future precision agriculture research and development. The research within Thrust 2 includes projects on power delivery, energy storage, backhaul communications, and sensor communications. The research projects range from generating new theory to developing devices to establishing and deploying communication protocols. There is an emphasis on developing foundational technologies that can be integrated into both Joint Ops and deployed across all of the IoT4Ag testbeds.

The distance to reliable power delivery infrastructure in agricultural applications can often be many miles, quite different from most other applications of IoT technologies. This challenge drives Thrust 2 research on power distribution and energy storage solutions that are designed to operate in the unique technical and environmental constraints of agricultural deployments.

Thrust 2 is approaching energy issues in IoT4Ag at two different scales. The smaller scale involves energy sources for deployed and/or buried sensors (4_AIR BATTERIES) with the ultimate intention of powering sensors from Thrust 1, both in terms of sensing modalities as well as active communication if required. The larger scale (12_ROBOT POWER) is aimed at extending the operational lifetime of unmanned ground and aerial vehicles employed in data collection. Within 4_AIR BATTERIES, we are exploring biodegradable chemistries suitable for soil and plant integration, while in 12_ROBOT POWER we are exploring both improving electrochemical power sources as well as rapid recharge infrastructure.

Project 4_AIR BATTERIES has continued its development efforts of biodegradable Zn-air batteries for powering active sensors. The batteries, referred to as “corn cells”, consist of thin Zn

foil anodes and catalyst-bearing paper cathodes encapsulated in wax (**Fig. 4D.13**). Last year, it was shown that the lifetime of the battery can be extended to 90 days under sensor relevant loads. Over the past year, improvements in battery performance were demonstrated that allow operation approaching one year. Key advances that enabled this approach include changing the chemistry of the gel electrolyte to a neutral pH, and carefully engineering the air paths in the battery to control carbonation.

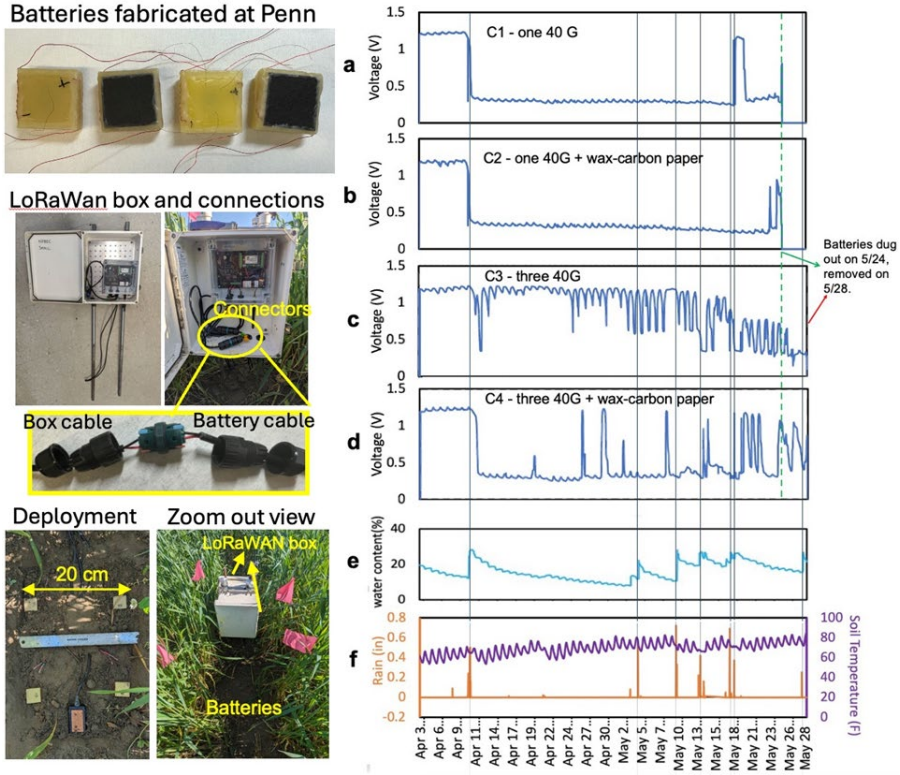


Figure 4D.13 (Left) Pictorial representation of field test biodegradable Zn-air batteries, LoRaWan box and connections, battery deployment under the soil at the UF testbed prior to and after burial (Right) (a)-(d): voltage of four batteries under discharge load being monitored and transmitted in real time by the LoRaWan box to researchers at Penn and UF; (e) record of soil moisture content at the test site; and (f) record of precipitation events (left axis) and soil temperature (right axis) at the test site.

Air batteries have been integrated with a LoRa communication gateway (7_EDGE COMP-COMM) through an interface circuit for deployment in the testbeds at Purdue (previous report) and UF (this report). Four batteries were deployed and tested in the UF testbed under the soil in Spring 2024, with an enhanced wax package design and improved electrical connections between different parts (**Fig. 4D.13**). The battery working voltage under sensor-relevant conditions was collected and analyzed together with the local soil temperature, soil moisture content, and local precipitation. It was observed that all batteries discharged at a nominal voltage of 1.2 V for approximately one week, until a heavy precipitation event. Although this precipitation event reduced the voltage of all batteries, one battery subsequently recovered. This observed sensitivity to excessive levels of soil moisture is attributed to impediments in the airflow. The daily fluctuation of battery working voltage is found to follow the temperature change over a day. Overall, the field test showed feasible battery operation for over a month and the field test information gained will be invaluable for the future design of robust under-soil biodegradable batteries.

Thrust 2 originally had two projects aimed at the larger scale energy needs of extending the operational lifetime of agricultural monitoring vehicles: advanced, high power and high energy density batteries for extended lifetime of aerial drones; and rapidly rechargeable electrochemical energy sources (and concomitant distributed charging infrastructure) for ground vehicles. Recognizing the synergies between these two projects, at the beginning of Year 4 they were merged into the single project 12_ROBOT POWER. This merged project is investigating (i) novel electrochemical power sources, including novel battery chemistries to expand drone flight duration

and novel supercapacitors for rapidly rechargeable ground robots; and (ii) distributed wireless recharging infrastructure for ground robots. This merger will allow us to cover the appropriate application space for data collection drones in IoT4Ag. Advances in each of these areas is described below.

Aerial Drones: To extend the operational flight duration of aerial drones, 12_ROBOT POWER is developing novel battery chemistries that simultaneously meet the high power density required to allow drones to take off and maintain flight, as well as the high energy density required to extend operational flight duration. High-energy density aluminum-air batteries (AABs) were specifically engineered for this purpose. Air batteries are particularly attractive for this application due to their intrinsically high energy density, potential for low packaging overhead (since isolation from the environment is less necessary), and the rapid discharge needs of drones obviating parasitic corrosion-based energy loss that plagues many conventional air batteries in other applications.



Figure 4D.14 (Left) A micro aerial drone powered by aluminum-air batteries (AABs). (Right) Flight duration comparison of conventional lithium-ion batteries (LIBs) to AABs; the flight duration of an AAB-powered drone is nearly triple that of a conventional LIB-powered drone.

Initially, a low-package overhead AAB fabrication technique was developed, resulting in the battery package contributing only 9% of the total cell weight, compared to over 30% in equivalent commercial LIBs. Additionally, the anode and electrolyte of the AABs are engineered to achieve an energy density of 320 Wh/kg above a power density of 500 W/kg, significantly outperforming commercial LIBs. A customized 3D-printed small-scale quadrotor platform is employed to evaluate flight duration, with the AABs delivering 13.1 minutes of flight time compared to the 4.5 minutes provided by commercial LIBs, nearly tripling the operational lifetime over conventional batteries (**Fig. 4D.14**). To our knowledge, this marks the first successful attempt at untethered powering of a quadrotor using air batteries. However, achieving the required power for the quadrotor necessitates using an expensive Pt-based cathode, which accounts for over 99% of the AAB cost. To address this cost issue, cost-effective high-power Ag-based cathodes were investigated. Through microfabrication, the power performance of the Ag-based cathode is enhanced by increasing its electrochemically active surface area. This cathode supports the necessary power density for the small-scale quadrotor while potentially reducing materials costs to 1/1500th of that of conventional cathodes.

Ground Robots: 12_ROBOT POWER researchers are developing strategies for rapidly charging both conventional batteries and novel supercapacitors in agricultural ground robots using a wireless scheme. For the wireless charging module, two prototypes were developed using two different off-the-shelf battery management systems to ensure the safe recharging of the batteries internal to robots. With these prototypes, the charge rate was determined to match that of the provided, wired charger, which operates at the maximum safe charge rate of the battery. Intrinsically, the efficiency for a wireless system is lower than that of a wired connection, but the wireless systems are completely enclosed and isolated from one another, which enables use in an outdoor environment, such as an agricultural field. A custom PCB was developed to simplify the system for the user. This PCB combines a streamlined battery management system, and an easily programmable microprocessor so that electrical characteristics such as charge rate and safety features such as maximum temperature can be easily controlled. Iteration has also been key to

improving the physical design of the enclosures for both the wireless power transmitter and receiver. A novel "backpack" model for the reception of wireless power that can be retrofitted onto existing ground robots has been developed that is both accessible to farmers and low-cost to produce and apply. This design choice enables the wireless charging module to be easily applied to robots already used throughout IoT4Ag, such as the Jackal UGV.

Wireless power transfer could also revolutionize electronics and sensors in the field. However, it is complicated by numerous issues. There is a strong desire for buried electronics, which could be charged through the soil. In addition, new agriculture devices may need to be charged over larger distances than those found in other applications. This all must be done under the constraint that human capital is expensive and precious in agriculture. For this reason, autonomous recharging of batteries at periodic intervals can minimize human intervention in replacing batteries. Project 11_CLUTTERED ENVIRONMENTS is working to address these problems. During Year 4, this project made advancements in using a rotating magnet receiver to power a buried soil moisture sensor system. For a given field amplitude at 12 cm, the rotating magnet transmitter provided around 2.4 times higher power output than the current carrying coil solution.

Sensing is critical to precision agriculture, and future use cases could utilize large numbers of sensors per acre. Ideally, these sensors could be located below the soil to accurately measure key soil properties and characterize under-soil plant behavior. Project 7_EDGE COMP-COMM aims to improve sensor communication and machine-based processing of the sensor data. Over the course of four years, this project has focused on advancing secure wireless communications and developing wireless power transfer (WPT) in underground communication systems for precision agriculture. In the first year, theoretical frameworks were developed to secure physical layer communications and to model efficient WPT in wireless powered communication networks (WPCNs). In the second year, the Avena software framework (which is also part of 16_AG COMM: Communication to Enable Agricultural Sensing) was developed to integrate communication equipment with edge-computing nodes in agricultural vehicles. By the third year, a platform was designed for assessing the feasibility of backscatter communications in above-ground to underground (AG2UG) scenarios, leveraging the ISOBlue edge-computer and the Avena software framework to implement the OATSMobile platform. In the fourth year, existing commercial RFID solutions were evaluated using OATSMobile, identifying implementation challenges in backscatter communications between edge computers and underground wireless sensor networks. Field testing was conducted at Purdue's ACRE Testbed to collect consistent data across different transponder types. Barriers such as proprietary protocol implementations in commercial RFID systems, and transponder fabrication tolerance were identified. The approach is shown in **Fig. 4D.15**,**16**.

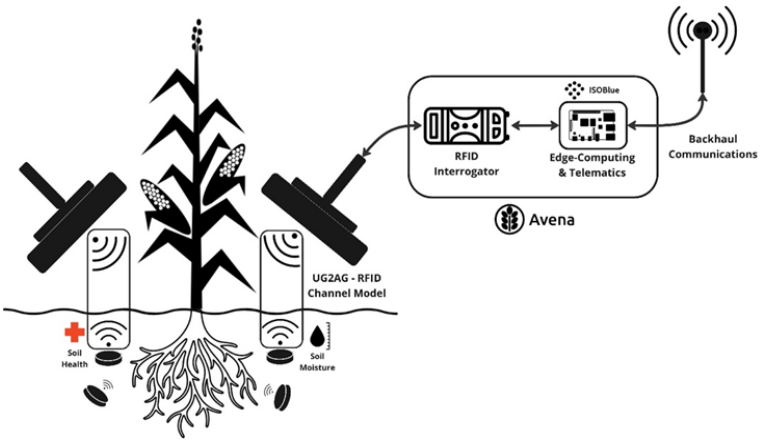


Figure 4D.15 A channel model for communication with underground transponders based on RFID technology. The sensor communication work feeds into the backhaul communication network.

We also continued our work on inductive communication+power transfer. A framework for inductive WPCNs was developed to maximize the efficiency of wireless power transfer using multiple-coil charging systems. Security is also important in sensor communication because low power devices often cannot support higher-layer techniques such as encryption. During Year 4, we continued our work on secure communication systems. Additionally, a characterization of RFID communication systems was performed through a series of controlled experiments that tested various factors affecting performance in AG2UG scenarios, such as transponder depth, size, antenna orientation, and channel multiple access. These achievements have laid the groundwork for further advancements in secure and efficient communication systems in agricultural and underground environments.

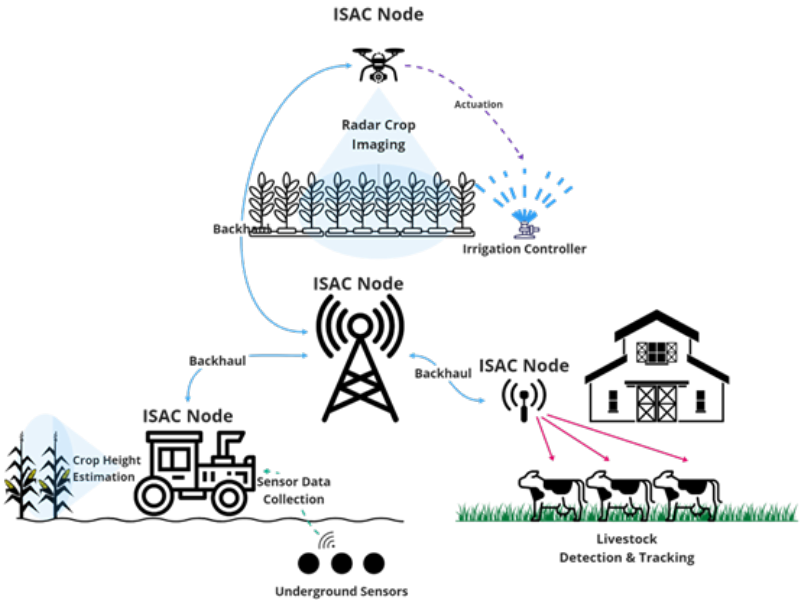


Figure 4D.16 The OATSMobile sensor communication, computing, and backhaul communications platform (left). RFID Sensors were deployed from the OATS Mobile for in-field testing (right).

The objective of 16_AG COMM is to design and optimize communication systems for rural agricultural sites, considering the unique constraints (e.g., latency and data rates) of agricultural applications. A key aspect of 16_AG COMM is integrated sensing and communication (ISAC) for agriculture (ISAC4Ag), which leverages communication nodes in agricultural sites (e.g., base stations, tractors, robots, and drones) for wireless sensing. In Year 4, we developed novel ISAC waveform design algorithms for high-resolution radar sensing (**Fig. 4D.16**). The radar capabilities of ISAC nodes can map the environment and thus enhance agricultural sensing such as vegetation monitoring and crop classification. Additionally, we advanced our research on backhaul communications to tackle the limited connectivity challenges in rural areas, aiming to improve uplink transmission for sensors and reduce the cost of backhaul deployment. Our research includes beamforming/precoding design for multi-hop networks and UAV-assisted backhaul, and performance analysis for lower power wide area networks (LPWANs). Lastly, we investigated machine learning-based channel modeling to gain a deeper understanding of rural channels, which is essential for optimizing communication systems for rural applications.

On the implementation/experiment front, we continued to improve our open-source framework for real-time field monitoring called Avena. Avena supports various types of data streams such as LTE, 5G-NR, LoRaWAN, cameras and Lidar sensors, enabling information fusion and data analytics. Moreover, we improved the communication aspects of OATSMobile to facilitate sensor/RFID data collection and transfer. Specifically, OATSMobile now supports 4G-LTE, Wi-Fi, and LoRaWAN through the integration with Avena and ISOBlue.

Robot swarms are likely to be used in future precision agriculture settings with imperfect communication and sensing. Unfortunately, the problem of navigating a swarm of robots to

accomplish a collaborative goal is challenging (e.g. see 10_PATH PLANNING) even in perfect communication scenarios. Swarm navigation problems require high-fidelity algorithms composed of perception, action, and communication. These are executed in a feedback loop usually called the Perception-Action-Communication (PAC) loop. Swarm navigation algorithms must be scalable to avoid bottlenecks, which motivated decentralized approaches. This decentralization, however, puts even further strain on the already limited communication capabilities. Project 29_ROBOT COMM aims to develop a learnable PAC architecture to address this problem. We have demonstrated a fully decentralized swarm model that scales with the environment and team size, called (LPAC). Our results have shown that LPAC performs significantly better than baseline centralized and decentralized algorithms on coverage problems.

Thrust 3 – Agricultural Response Systems.

Thrust 3			
Name	Role	Department	Institution
Buckmaster, Dennis R.	Thrust Co-Leader	Agricultural & Biological Engineering	Purdue University
Crawford, Melba	Faculty	Civil Engineering	Purdue University
Hestir, Erin	Faculty	Civil & Environmental Engineering	University of California, Merced
Keske, Catherine	Faculty	Management, Innovation, Sustainability, Technology	University of California, Merced
Koppal, Sanjeev	Faculty	Electrical and Computer Engineering	University of Florida
Messina, Charles	Thrust Co-Leader	Horticultural Sciences	University of Florida
Ribeiro, Alejandro	Faculty	Electrical and Systems Engineering	University of Pennsylvania
Yeo, Melanie (Lisa) L.	Faculty	Management of Complex Systems	University of California, Merced
Zare, Alina	Faculty	Electrical and Computer Engineering	University of Florida

Year 4 Accomplishments*:* IoT4Ag aims to transform the industry by integrating sensing, transmission, and translation of data into knowledge by building tools for asking what-if questions, which enable decision making. IoT4Ag has a deep commitment to understanding and addressing the needs of the agricultural community by engaging with farmers, extension advisors, and decision makers. To this end and with technology adoption in mind, Thrust 3 addresses data interoperability and data fusion by employing biophysical models, artificial intelligence, and digital twins to enable analysis and decision making systems related to nutrient management, water, and pests in cropping systems. In this section, we report progress made in Year 4 in Thrust 3 and highlight how individual projects contribute to the broader goal of creating a toolset to enable farmers to create strategy and activate tactics in agricultural systems.

The integration of diverse data streams is a cornerstone of IoT4Ag and is the key goal of Project 27_DATA INTEGRATION. We have developed a comprehensive framework for collecting and integrating data from a variety of sources including farm machinery, soil, plant, and water sensors,

public databases containing weather information and SSURGO soil surveys, etc. Importantly, this framework also enables the integration of contextual metadata into a single, interoperable platform. The data integration process begins with the conversion of diverse data formats into streamed atomic messages, a method designed to ensure seamless compatibility across systems (**Fig. 4D.17**). This approach addresses the inherent variability in data sources, such as differences

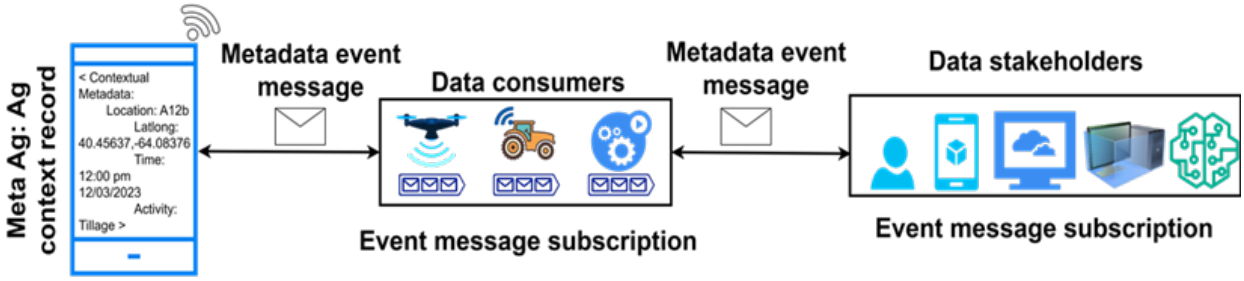


Figure 4D.17 Connection diagram illustrating the process of converting diverse data formats into atomic messages and integrating them into a unified data stream.

in spatial and temporal resolution, which can complicate the alignment and fusion of data from multiple origins. By standardizing data into a common atomic format, the project creates a unified stream (hence also datasets) that can be efficiently utilized in various models and decision support tools, thereby enhancing the accuracy and timeliness of agricultural decisions. In the coming year we will realize real-time decision flows with the IoT4Ag data pipeline and develop the first rudimentary machine learning-based decision support tools.

Project 22_DATA FUSION approaches the problem of integrating data sets of disparate temporal and spatial resolution in order to enable the creation of data stacks that are actionable and usable for modeling purposes (**Fig. 4D.18a**). The approach is applied to the integration of satellite remote sensing data, UAV data, and ground-based observations, which is needed for hybrid, multi-sensor analytics and decision-making tools able to leverage the advantages of different sensing platforms. For example, satellite remote sensing provides broad coverage and frequent revisit times, making

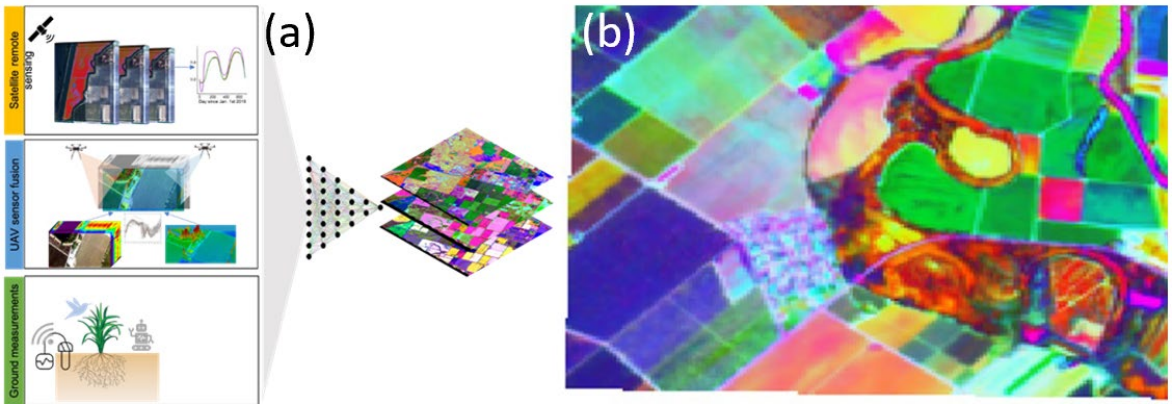


Figure 4D.18 (a) Diagram illustrating the integration of satellite, UAV, and ground-based sensor data in the hybrid approach, highlighting the complementary strengths of each data source. (b) Example of a drought stress detection map generated using the hybrid approach, showing early warning indicators based on integrated multi-source data.

it ideal for large-scale monitoring. However, satellites often lack the spatial resolution needed to detect fine-scale variability within fields. UAVs offer high-resolution imagery, capturing detailed information about crop health, canopy structure, and other critical parameters though their limited coverage area, high operational costs, and regulatory constraints make them less suitable, with today's technology, for monitoring large expanses (i.e., regional or county-wide) of farmland.

Ground-based sensors, on the other hand, provide continuous, real-time data on soil moisture, temperature, and other environmental variables, but their measurements are often point-specific and may not represent the entire field or orchard. In Year 4 Project 22_DATA FUSION has successfully demonstrated the estimation of vegetation fractional cover with high spatial (e.g., 10 m) and temporal resolution (e.g., daily), which is critical for monitoring crop health and detecting stress factors such as drought or nutrient deficiency. **Fig. 4D.18b** shows the results of the fusion algorithms providing a precise mapping of water stress with both resolution and large area coverage. This allows issues to be identified early enough to enable timely mitigation.

Project 33_NUTRIENT MANAGEMENT aims to leverage IoT, advanced sensing, and predictive modeling to enable new approaches to the sustainable management of nutrients in major cropping systems. A key project advancement is the development of methods to enable strategic sensor placement within fields and small catchments. Sensor placement is crucial because it directly impacts the accuracy and efficiency of nutrient management practices. The fundamental tradeoff between dense low cost sensors and sparse high cost sensors is still not sufficiently understood. In Year 4 we improved a Soil and Water Assessment Tool (SWAT) to help explore the fundamental tradeoff, which largely depends on cropping system complexity and sensitivity to initial conditions. SWAT uses a robust model to simulate water and nutrient flows in three dimensions, considering factors such as elevation, soil type, land use, and the biophysical properties of crops. A critical project innovation has been the integration of SWAT with Deep Learning which was introduced in Year 4 to improve the simulation of water balance (**Fig. 4D.19**), which is fundamental to accurately simulating the soil-plant nitrogen (N) balance, which is a key component of nutrient management. Certain forms of nitrogen are mobile in the soil with water. Other forms are susceptible to volatilization with water excess.

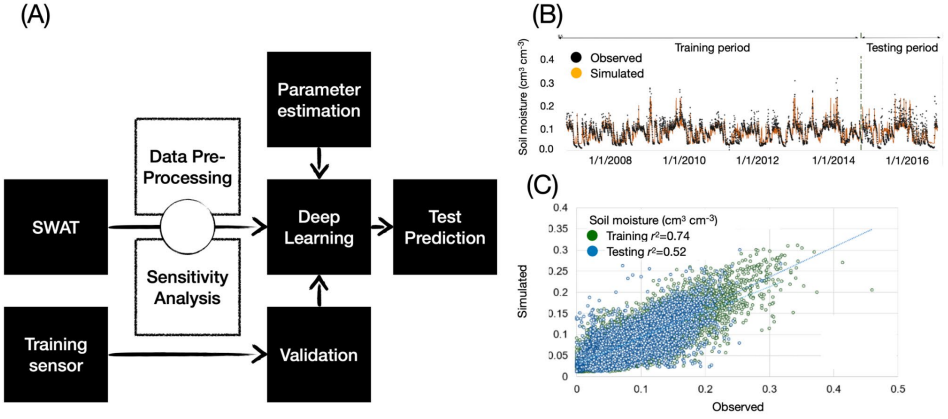


Figure 4D.19 Schematic of process used to fuse the biophysical model Soil and Water Assessment Tool (SWAT) with deep learning to improve soil moisture predictions.

Project 24_BIOPHYSICS focuses on real-time decision support based on actual conditions of the growing season. With key operational inputs and location-based soil and weather information



Figure 4D.20 Flowchart of the overall approach illustrating different stages and processes of user-interface design, starting with gallery walk and voting methods, to user-interface creation, and followed by the final agreed version of a within-season management tool.

driving a well-documented biophysical model (APSIM), improved tactical decisions that consider crop yield and environmental impacts can be made. **Fig. 4D.20** documents a workshop exercise for the project's management tool. One of the key milestones for Year 5 is to add on-farm IoT data flows (renaming 24_BIOPHYSICS to 24_PREDICTIVE_MODELING). By leveraging the integrated data framework (27_DATA INTEGRATION), data fusion (Project 22_DATA FUSION) and modeling framework (33_NUTRIENT), the project aims to support decision-making processes that are informed by comprehensive, up-to-date information. Instead of deploying large, computationally intensive models directly on edge computing devices, the integration schema allows for decision-making through data requests. This architecture significantly reduces the computational load on edge devices, enabling faster and more efficient decision-making. Machine learning plays a crucial role in this system by enabling the development of decision support models that can process the integrated data and generate actionable insights. Tactical decisions via real-time recommendations to farmers include irrigation scheduling, nutrient application, and crop protection. The goal is to integrate these ML-driven decision support models seamlessly into the IoT environment, creating a robust system that can adapt to the dynamic conditions of agricultural environments.

Project 32_SPRAY SYS focuses on the within and among season factors (**Fig. 4D.21**) for peanut fungal diseases. By varying different winter field management practices and with insights from in-field environmental sensors and multispectral drone imagery, disease development and plant health can be predicted. Action thresholds have been identified and the decision support tools regarding fungicide inputs are under development. The combination of empirical data from novel sensors, AI detection, and automated data integration enable this integrated system. In the coming year, 32_SPRAY SYS will add computer simulation to model airborne movement of pathogens and a combination of imagery algorithms and CROPGRO-peanut to quantify growth, defoliation, and yield with validation from ongoing field studies in varied environmental conditions and soil properties.

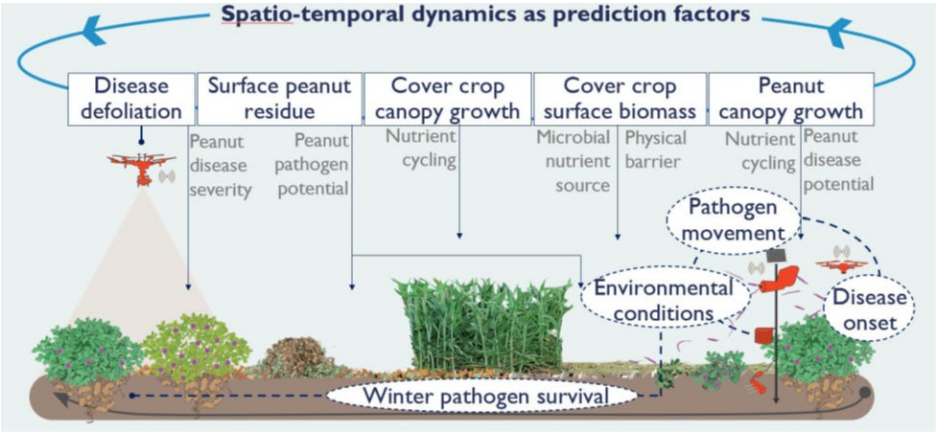


Figure 4D.21 Peanut fungal disease factors.

Project 28_TECH ADOPTION has played a pivotal role in engaging the stakeholders for IoT4Ag's technological innovations by improving our understanding of barriers to technology adoption and exploring their mitigation. Through in-depth interviews and interactions with California tree-nut farmers the project has underscored the critical importance of building trust. When farmers are directly involved in the process of technology development, a sense of ownership is fostered and technical solutions are better tailored to specific needs and economic reality. A sense of ownership and trust, which will facilitate adoption can be gained by involving farmers in beta testing and demonstrating technologies in university trials. In addition to engagement efforts, Project 28_TECH ADOPTION has also explored the complexities surrounding data sharing, particularly in the context of increasing reliance on AI for decision-making in agriculture. The project has

recognized that trust in data governance is crucial for widespread technology adoption (**Fig. 4D.20**). To this end, it has been investigating the role of data monetization and has begun developing equitable data governance frameworks. These frameworks are designed to address concerns related to data privacy, security, and the perceived proprietary nature of data, while also creating a more transactional and transparent approach to data sharing. The ultimate goal is to establish a trustworthy and efficient data-sharing ecosystem that benefits all stakeholders, ranging from individual farmers to larger agricultural enterprises. By understanding both the tangible economic benefits and the intangible trust issues associated with data governance, the findings in the project can help inform development and deployment strategies. These efforts are crucial for ensuring that the innovations developed are not only technically viable but also adopted for use in the field.

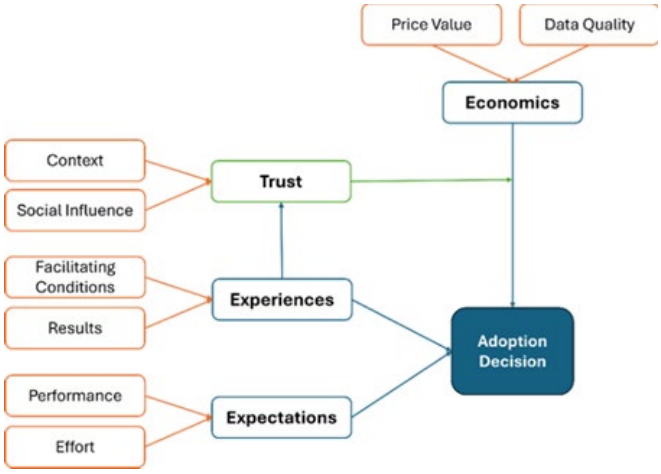


Figure 4D.22 Conceptual model adoption decisions toward Ag technologies.

CONVERGENT RESEARCH IN YEARS 6-10

Vision: IoT4Ag has built a vibrant, multidisciplinary, convergent research effort over the past four years. This includes research on advanced hardware for next-generation precision agriculture systems, including sensors, robotics, communication approaches, and power technologies, in Thrusts 1 and 2. In parallel and in close collaboration with the other thrusts, researchers in Thrust 3 are developing data-driven models, sensor fusion approaches, and models with farmer-centered interfaces that allow for decisions to be made based on diverse data streams from multiple sources, including deployed sensors, drone and satellite imaging, weather data, and historical information. Cross-cutting research projects that engage farmers and growers to understand economic and other barriers to technology adoption are ongoing to ensure that IoT4Ag technologies are created and designed for diverse end-users. The research activity in the Center broadly covers the fundamental knowledge, enabling technologies, and systems needed for next-generation agriculture, as noted in the three-plane diagram (**Fig. 4D.2**) and 10-year milestone chart (**Fig. 4D.4**). The Center has many research accomplishments through Year 4, as detailed in this report. In Year 5, most of the efforts from Year 4 are continuing with some adjustments in project scopes, as informed by the annual needs assessment and annual project review cycle.

IoT4Ag's priority in Years 6-10 will be the demonstration of end-to-end integrated systems that combine IoT4Ag technologies to address critically important problems in agriculture (e.g. nitrogen management, water use, pest and disease mitigation). We will build on our research accomplishments to date to combine existing agricultural data sources and hardware with novel IoT4Ag sensors, robotics, communication, and power solutions in integrated systems. These systems will inform AI-driven digital twins for row and tree crops and provide human-centered decision-Ag interfaces for agricultural management. The research portfolio in Years 6-10 will continue to have a mix of projects that span from fundamental knowledge to enabling technologies to integrated systems (**Fig. 4D.2**), but we will emphasize field testing of systems in the Joint Ops.

The realization and testing of integrated systems in field trials are critical for demonstrating the 10-year vision of IoT4Ag technologies to farmers, stakeholders, and the scientific community.

Data is key to enabling AI models for agriculture, and IoT4Ag is creating and deploying sensor networks that will provide data with the necessary spatial and temporal resolution for data-intensive models. IoT4Ag Joint Ops will generate large datasets from multi-year field trials. This data will be used to create IoT4Ag digital twins of row and tree crops and will also be made publicly available to allow other research teams to develop and test their own AI-driven precision ag models. Since IoT4g was established in 2020, there have been tremendous advances in AI and there are multiple new efforts in AI for agriculture supported by NSF, USDA, and others. IoT4Ag efforts in AI have evolved as the landscape has changed and our efforts in this space continue to be at the forefront. A defining and unique feature of IoT4Ag relative to many other efforts in AI for agriculture are the Center's efforts to build and deploy the next-generation hardware needed to collect data in fields and orchards while concurrently developing AI-based digital twins and decision-ag models.

Organization and Prioritization of Convergent Research Activities: In Year 5, there are 22 projects in the center. Of these, 16 projects are focused on advancing knowledge and platform technologies that will serve multiple Joint Ops. The projects are distributed across core technology areas and can coarsely be categorized as 4 in sensors, 3 in robotics, 2 in communication, 3 in power, 1 in data integration/fusion approaches, and 2 focused on end-user engagement and adoption. The other 7 projects are more strongly oriented towards collecting data from the field and developing data-driven approaches needed to make agricultural decisions (i.e., Projects 17, 18, 20, 22, 24, 32, 33). To strengthen the Joint Ops in Years 6-10, these 7 projects will be positioned primarily in a relevant Joint Op and play a key role in leading and organizing the Joint Op in collaboration with the testbed lead. To focus our efforts on delivering in the Joint Ops, we will align each Joint Op with a primary testbed location:

- Joint Op 1: Integrated Systems to Optimize N Application in Row Crops will be implemented at the ACRE facility at Purdue, and IoT4Ag systems will be used to guide responsible nitrogen use in corn and soybean production.
- Joint Op 2: Integrated Systems to Optimize Water Use in Tree Crops will be implemented at the University of California-Merced and used to guide the irrigation of almond and pistachio orchards.
- Joint Op 3: Integrated Systems to Mitigate Disease and Pests will be implemented at the University of Florida with an initial focus on detecting and mitigating aflatoxin in peanuts.

Each one of these Joint Ops represents a major challenge facing farmers and growers in the US and the world today and thus serves as an excellent vehicle for demonstrating the opportunities presented by IoT4Ag technologies. These efforts will lead to large, multi-year datasets from seasonal field trials in each of the Joint Ops and demonstrate the capabilities of IoT4Ag hardware and algorithms.

While we will focus certain projects and testbed locations toward a single Joint Op to facilitate the realization of end-to-end systems, we fully expect that technology and approaches from all projects will be shared across the center and that advances will not be siloed in an individual Joint Op.

Research projects focused on advancing fundamental knowledge and enabling technologies in sensors, robotics, power, communication, algorithms, models, and adoption will continue and

contribute technologies to one or more Joint Op (we will prioritize projects that serve multiple Joint Ops and fill technology gaps). The current suite of projects spans a range of ARLs and TRLs. In Years 6-10, we will continue to have a portfolio of projects that includes lower TRL/ARL efforts aimed at advancing fundamentals as well as higher TRL projects that are field-deployed. The portfolio will be weighted towards higher TRL/ARL projects (i.e., 4 to 6) as these projects are crucial for successful execution in the Joint Ops. A suite of high-risk/high-reward projects at lower TRL/ARLs will be maintained to investigate and invent new technologies with the potential to transform precision agriculture over a longer time horizon.

Research Projects and Thrusts: In Years 6-10, some projects will continue, new projects will be created, and others will be sunset. Here, we highlight future research in the context of specific projects and Thrusts as *representative examples* of future activities. Projects will continue to be reviewed each year, and the project portfolio will be refreshed annually to ensure that research in the Center is at the forefront of the field and aligned with the needs of the Joint Ops and stakeholders (**Fig. 4D.3**).

As noted above, multiple projects in the Center are positioned to integrate technologies and data streams within the Joint Ops and demonstrate the impact of IoT4Ag integrated systems. The advances in these projects to date position them to play leading roles in the Joint Ops in Years 6-10. Projects 20_CORN MASS N2, 24_BIOPHYSICS, and 33_NUTRIENT MANAGEMENT are central to Joint Op 1 and will develop predictive models and decision interfaces for corn and soybean yield based on a number of different data streams. Projects 17_ORCHARD and 22_DATA FUSION are central to Joint Op 2 on water and will use a combination of distributed sensors, robotics, and satellite imaging to assess water needs and make irrigation decisions in orchards at the UC Merced testbed. Projects 32_SPRAY SYS and 18_SENTINEL are aligned with Joint Op 3 and will assess new approaches to disease and pest management, with an initial focus on early disease detection in peanut crops. The organization of the Joint Ops is detailed below in the **Joint Op Selection, Structure, and Examples** subsection.

In addition to these system-level projects, technology research and development will continue in all thrusts. This work will build on the 16 projects in Year 5, noted above, that are focused on investigating and advancing knowledge and core technologies. These technologies cut across the Joint Ops, and new capabilities developed within these projects will be integrated into the testbeds as the projects mature and advance the data capture, transmission, and analytics capabilities within the integrated systems. The Thrust descriptions below provide examples of directions that will be pursued but are not meant to be comprehensive.

Thrust 1 will focus on advancing sensor technologies and robotic systems for collecting data in fields and orchards. We will continue to develop on-plant multi-stress colorimetric sensors capable of detecting various measurands like temperature, VOCs, and toxins in a single device. An autonomous robot fleet equipped with imaging suites will be developed to locate, measure, and map plant health using these sensors. We will extend the capability of our biodegradable wireless sensor platform to measure additional soil parameters such as nitrate, ammonia, and pH. Both passive and active sensing modalities will be explored, with efforts to tailor sensor lifetimes for different crop types, ranging from a full growing season for row crops to up to a decade for certain tree crops. We will work on integrating these sensor technologies with autonomous robotic systems for large-scale, long-duration deployment, and data collection. This includes developing fleets of agricultural robots capable of collaborative operations, sensor deployment, and data gathering across entire growing seasons. Research will also advance robotic localization, mapping,

and decision-making capabilities in diverse agricultural environments. AI tools will be leveraged to assist in mission planning, code generation, and system design, with the ultimate goal of creating fully autonomous robotic teams that can optimize resource use and farm management decisions based on comprehensive, real-time data collection throughout the crop growth cycle.

Thrust 2 will focus on advancing near-optimal communications and energy solutions for agricultural environments, with the goal of creating a robust infrastructure and research base for precision agriculture comparable to those found in well-established industrial facilities. In the area of power systems, we will continue work on biodegradable batteries with the aim of developing air-independent chemistries that can operate deeper in soil, and be less affected by environmental conditions. We will optimize full-cell air-less configurations, including low-cost manufacturing and electrolyte chemistry, to match the needs of long-term buried sensors. We will also continue to investigate new strategies for rapid wireless charging of deployed sensors and devices. For communications, the research will expand in several fundamental directions. Non-terrestrial networks (NTNs) and multi-hop communication backhaul networks will be explored to provide stable connections in areas with sparse cellular coverage. This will involve developing new waveforms tailored for agricultural use cases that can operate alongside existing satellite and UAV network applications. A comprehensive performance analysis of multi-hop backhaul communication networks will be conducted to facilitate the transport of aggregated data from sensors and farm vehicles to decision centers. Additionally, we will emphasize multimodal communications, using plants as sensors to derive insights into environmental field properties such as soil moisture and nutrient availability. We will also continue to explore underground backscattering, a non-invasive technique that monitors environmental parameters sustainably.

Thrust 3 will focus on data-driven biophysical models and digital twins able to inform farm management decision systems that use advanced ML/AI algorithms to prescribe crop treatments involving nutrients, water, and crop protection. Thrust 3 will maintain a focus on the essential constraints of logistics, labor, cost, and environmental impact. The research in Years 6-10 will involve data standards, spatial and temporal data alignment, data fusion, and crop simulators. IoT4Ag sensors provide data as point measurements at many spatial and temporal resolutions and as images from multi-spectral cameras and Lidars mounted on UGVs and UAVs. Data from public sources for soils, topography, weather, and satellite remote sensing are also used. These have various standards, variable quality, and widely differing spatial resolutions and time sampling, which requires alignment, synchronization, interpolation, and decimation depending on the case. Several Thrust 3 projects are working to provide this capability to allow data fusion to proceed. Through several additional projects Thrust 3 will build biophysical crop simulators that capture the varying soils and topography of a physical farm field or orchard along with the stochastic nature of weather and other inputs. The whole system is needed to model a crop with “pixels” of sufficiently fine resolution that prescriptions can be written allowing environmentally responsible use of nutrients, water, and pesticides as constraints in an optimization of overall farm profit. Thrust 3 also promotes the full path toward adoption which is largely based on economics and trust better understood via research on data monetization, data sharing models, and training needs in the industry.

Joint Op Selection, Structure, and Examples: The 10-year vision of IoT4Ag will be demonstrated through the Joint Ops. Below, we explain the motivation, value proposition, and structure of the three Joint Ops we will initially focus on in Years 6-10. These three Joint Ops were selected early in the life of the Center because of the importance of the problems and the potential

broad impact of new solutions. We will solicit ideas and proposals for new Joint Ops annually, and decisions to launch new Joint Ops will be made by the Executive Committee based on input from the SAB and IPAB/ASAB as part of the annual project review cycle. We expect that the three initial Joint Ops will need to run for 2-3 years to accomplish their goals, and finite resources are likely to prevent launching a fourth Joint Op in parallel. However, we will consider Joint Op proposals on an annual basis to ensure that the Center is being responsive to national and global needs (e.g., the Center could pivot to a new Joint Op quickly if an emerging critical problem was identified) and to develop a plan for the Joint Ops that will succeed the current ones in the later years of the Center.

Joint Op 1 on Integrated Systems to Optimize Nitrogen Application in Row Crops is implemented at Purdue's ACRE testbed. Water runoff into tile lines and streams and infiltration into groundwater containing unused nitrogen and phosphorus is a significant environmental concern because of links to dangerous algal blooms in midwestern lakes. The situation is aggravated by rising average temperatures, increasing carbon dioxide concentrations, and the growing frequency of large rainfall events. Excess nitrogen can also be denitrified as the greenhouse gas N_2O, which is a potent source of warming.

Indiana does not regulate nitrogen fertilizer application with the exception that certain setbacks are required from drainage ditches, wells, and streams, which apply to manure applications from confined feeding operations. However, many Indiana farmers follow Purdue recommendations which account for the fact that the corn yield curve always saturates as a function of applied nitrogen. Typically, the nitrogen application rate which maximizes economic return is below that where the yield curve begins to flatten. The Purdue guidelines vary spatially (and coarsely) across the state depending on the average climate and the average soils. However, they fail to address year-to-year in-field spatial variability meaning many in-field areas result in over or under application.

In response to recurring algal bloom events in Lake Erie, regulations on nitrogen and phosphorus fertilizers across the state line in Ohio are stringent and specific. Ohio fertilizer application regulations are spatially and temporally dependent and a function of three features: 1) the classification of the soil into one of four hydrological categories, 2) the county's average annual rainfall, and 3) the county's rainfall outside of the growing season. In addition, Ohio considers the local water table level and whether or not a field is tile drained. In the case of phosphorus Ohio also regulates based upon soil test results.

Precision ag systems today allow midwestern farmers to prescribe fertilizer spatially at preplant and in-season via sprayers, nitrogen applicators, and pivot irrigators, yet it is still very difficult to inform these prescriptions with the expected return and an assessment of the risks of different decisions. Farm business decisions focus on profitability. However, farmers are first and foremost managers of the logistics of growing crops. Every decision must be understood in terms of its logistical impact. In the case of in-season nitrogen application there are costs associated with additional field operations and risk associated with the weather and the relatively short window available for application. For Joint Op 1 to have impact it must address these bigger picture issues, which is why a broad spectrum of research is involved and why we must integrate from sensing to adoption to understand how to design the end-to-end system.

Despite its complexity Joint Op 1 presents a substantial opportunity for IoT4Ag research. The current regulatory model for nutrient management is not going to work. The spatial resolution

needs to improve by at least 4 orders of magnitude from the county-wide regulations currently applied in Ohio. This is the minimum resolution needed to properly account for interconnections to the fine scale watersheds in the Midwest. This would amount to a spatial resolution with "pixels" on the order of 10 hectares. Furthermore, the temporal resolution of regulations needs to account for daily or weekly variations in rainfall, not an average of an average season. In hundreds of field trials carried out by Purdue researchers over a period of ten years, it was observed that the agronomic optimal rate of nitrogen application varied by more than a factor of 2 in the same plots in different years. Regulation with a single allowed application rate, even if spatially varying, will either be so low that it substantially reduces yield in many years, or if targeted to support a minimum economically viable yield in most years, will often leave about 50% of the applied nitrogen in the field. To avoid this quandary will require IoT4Ag technologies to provide high spatial and temporal nutrient state information integrated with crop models with high spatial resolution. Then it would be possible to regulate nitrogen and phosphorus with sufficient spatio-temporal resolution while simultaneously adapting to the growing conditions in a field or sub-field.

Figure 4D.23 depicts the relationships between IoT4Ag projects currently involved in Joint Op 1. Additional projects will be added as they mature, and the need arises. Sunsetting projects are included in the Joint Op because the algorithms developed will still be used in the overall system integration. The idea of the diagram is to show the data flows needed to implement an end-to-end system. At present in Year 5 all the low-rate flows are implemented in the ACRE testbed. The

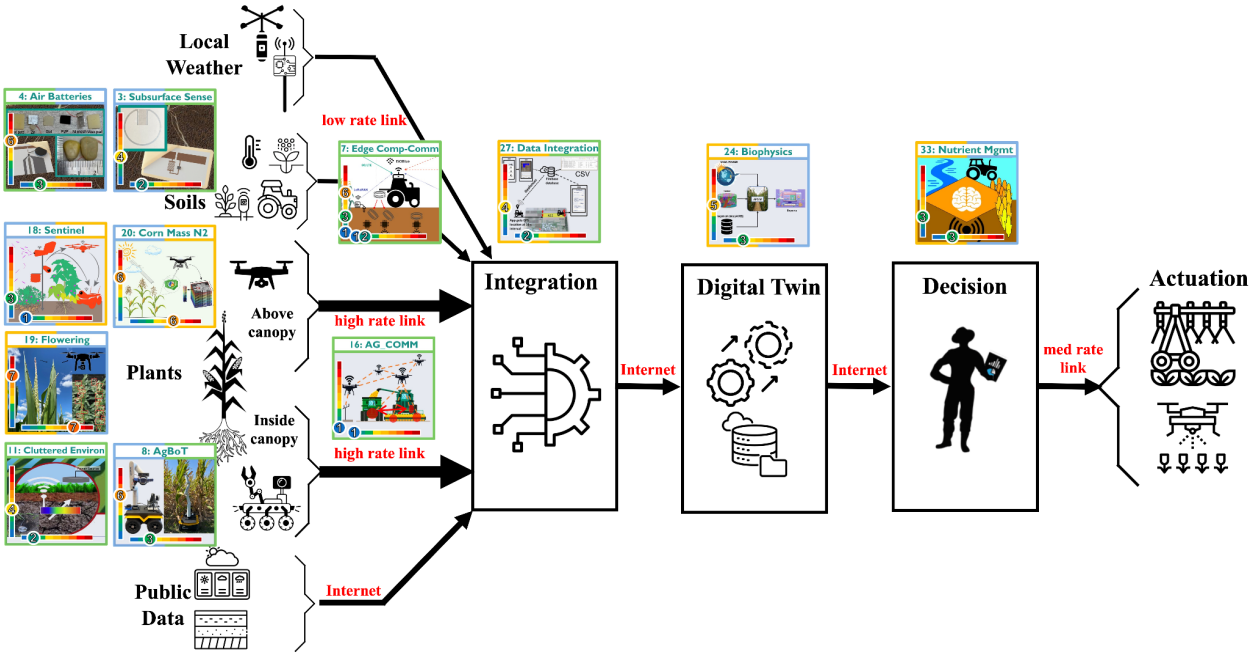


Figure 4D.23 Illustration of Joint Op 1 as data flows between IoT4Ag projects and integrations.

high-rate data flows from imaging sensors on UAV and UAS platforms are only partially automated. Their full automation is the main goal of the communications research in Thrust 2 over the next few years. Sensor systems for soils and plants are indicated on the left side of the figure along with projects supporting the powering of the sensors. Subsurface sensors allow direct measurement of many soil parameters important to understand the state of nutrients in the soil and therefore provide a key part of the data needed to regulate in-season fertilizer applications. The density of such sensor deployments is a topic of research and modeling that will be understood in

the context of the end-to-end system. Allowing for redundancy and averaging to reduce noise we expect soil sensor deployment densities on the order of 100 per hectare to allow for soil and organic matter variability.

The imaging sensors associated with three of the projects produce data at rates that would challenge the latest WiFi standards, meaning that streaming their data in real-time at field scale is impractical today. However, Thrust 2 research is investigating beyond 6G communications and methods of network extension that will eventually fill the gap. Until those are practical, however, we can use the testbed's low-rate network to help automate the acquisition of imaging data by managing associated meta-data and by providing the edge computing needed to process images to much lower rate "detection events."

Data integration is at the center of the Nitrogen Joint Op dataflow with research of procedures for converting disparate data types into standardized "atomic" messages, which are handled by the Avena/NATS (Neural Autonomic Transport System) messaging system. The focus on these simpler event-based data flows allows standardization simplification and avoids requiring the testbed to manage large data stores – instead the testbed provides data flows from sensors to data integrators to biophysical models to decision systems. Data users from inside or outside ERC can subscribe to data flows at any point in the block diagram (with permission), but they are responsible for their own data storage.

The Joint Op uses digital twins based on crop growth models coupled with techniques from ML/AI to create recommendations for treatments, e.g., spatio-temporal prescriptions for in-season nitrogen application. In order to create prescriptions with high spatial resolution, crop modeling algorithms such as APSIM and DSSAT need to be implemented as a massive parallel set of "pixel" simulations where "pixel" interconnections are governed by topography and soil hydrology. Simulations of this nature will likely make use of parallel computational capabilities in GPUs. The size of a corn field "pixel" might well be on the order of 1000 plants meaning there would be about 100 per hectare. This capability is needed to understand the nutrient state of a corn field and determine the need for and risk associated with a nutrient application on a particular day.

Purdue University Testbed: The Purdue IoT4Ag testbed is located at the Agronomy Center for Research and Education (ACRE), a 1600 acre farm a few miles from the campus in West Lafayette, IN. About half of the farm is planted each year in research trials, and the remainder is farmed with uniform treatment and rotated with the research plots. The primary research crops at ACRE are corn, soybeans, sorghum, wheat, and popcorn. The ACRE facility is well equipped for deployment of IoT4Ag technologies. Power, networking, and weather monitoring equipment are reasonably well distributed around ACRE. Networking uses two 10 Gb fibers to connect with the main Purdue campus, providing capability to transfer data to campus and utilize the university computing clusters. Verizon and AT&T provide good LTE coverage over the farm's outdoor areas, and WiFi has been installed on multiple towers on the farm. A 16-channel Tektelic LoRaWAN gateway was also deployed at 25 m elevation on the ACRE weather tower.

As part of Thrust 2, communication infrastructure has been developed and tested at the Purdue testbed. Purdue IoT4Ag researchers have developed the IsoBlue Avena software stack, which integrates several open-source applications (Linux, Docker, NATS, Wireguard, Grafana, and ThingsBoard) to create a sensor data messaging system, which can be deployed across the universities, testbeds, agricultural machines, and fixed sensor installations. Purdue OATS DataStations (PODs) consisting of a Linux computer running the Avena software stack, a

LoRaWAN gateway, and backhaul connections provided via LTE, WiFi, or wired ethernet if available, were developed and shipped in Year 2 to the UF for integration with their testbed and to the Morris Arboretum as part of community outreach. In Year 3, several PODs were deployed to acquire soil sensor and environmental data to support a UF/Purdue collaboration. Digital Matter Oyster GPS devices, which report to the Tektalic gateway and the PODs, have also been deployed onto almost every moving machine that operates at ACRE. These report location coordinates, altitude, and speed once every 5 seconds. At the gateways RSSI, data rate, and packet loss information has been collected all season, which is used for large-scale study of propagation on the ACRE farm.

Joint Op 2 on Integrated Systems to Optimize Water Use in Tree Crops is implemented at the University of California-Merced and used to guide the irrigation of almond and pistachio orchards. California is the top agricultural state in the United States by value of the crops produced and is one of the heaviest users of irrigation in the world. While there are common environmental themes playing out in California and Indiana, the per acre value of the land, water, and crops produced in California is much higher than in Indiana or elsewhere in the Midwest. The average value of farmland in Merced County, California, is a factor of three or four higher than in Tippecanoe County, Indiana. The multiplier is even larger in the lettuce growing areas near Salinas in Monterey County. Yet, with the exception of a few California "twists", many of the issues facing Merced and central Indiana are the same: loss of fertilizers and pesticides into the environment, labor shortages, logistic challenges, and thin profit margins. In the Central Valley, there are three related issues which the Joint Op will address using IoT technologies. These are salt accumulation contaminating soils, nitrate contamination of groundwater and its effects on the drinking water of nearby communities, and water use efficiency. On average, California uses about 3.5 feet of irrigation water per year, on over ten million acres, which is about equivalent to the rain supplied by water falling on central Indiana each year. There is one very important difference however which affects both the types of crops grown and the solutions that should be applied for environmental sustainability. With irrigation in an otherwise dry growing season climate, California is largely in control of water and can apply it spatially and temporally for optimum effect. In the Midwest of the United States, it rains randomly. There is enough average water in Indiana to grow Romaine lettuce, but the inability to control it when it rains makes it very nearly impossible to compete on quality and uniformity. This largely explains the difference in the value of farmland between the two testbeds. In addition, because in-season water is controlled in the Merced testbed, the most effective way to address water quality issues is through water use efficiency. Also, with ongoing droughts and new regulations called the Sustainable Groundwater Management Act (SGMA), which limits groundwater extraction, it is vital to improve water use efficiency, especially for tree crops in California. Almonds, which require significant water, are mainly grown in arid regions of San Joaquin Valley, making efficient irrigation critical to sustain production. Developing new technologies that improve water management strategies, such as precision irrigation, help maintain long-term productivity despite reduced water availability.

Figure 4D.24 depicts the relationships between IoT4Ag projects currently involved in Joint Op 2. Additional projects will participate as the need arises and certain projects will sunset when the research is complete. If such a project produces algorithms or software used in the Joint Op integration, it will continue to participate in the Joint Op. In addition, some projects appear in more than one place in the flow diagram if they contain subprojects distinctly separated in function, e.g., a project which develops a sensor technology in one part and an algorithm for interpretation or decision making in another part. In this description we focus more on the integration and the value of a project for the Joint Op. This is not meant to replace the detailed project descriptions found elsewhere in this report. Finally, if projects were described previously, they won't be explicitly mentioned here unless their use has changed.

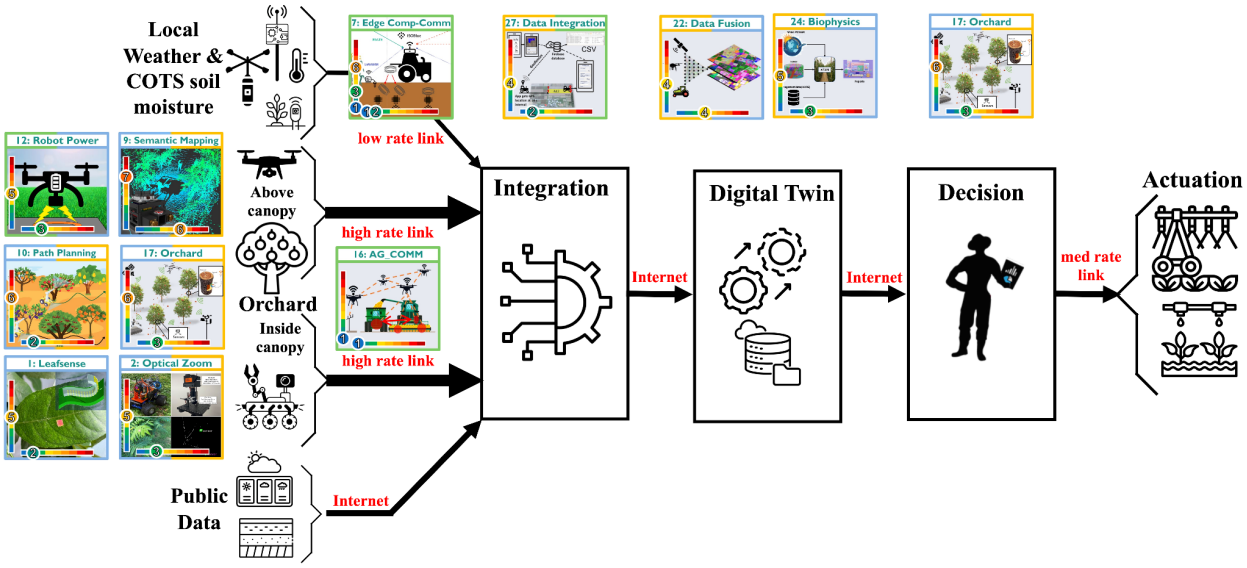


Figure 4D.24 Illustration of Joint Op 2 as data flows between IoT4Ag projects and integrations.

Sensor systems for trees are indicated on the left side of the figure and are of two distinct classes: 1) point sensors attached to leaves or trunks and 2) proximal sensors associated with UAV/UGV imaging systems. In the first category we have a project developing optical metasurfaces that can form the foundation of a variety of biodegradable sensors related to plant properties expressed on plant leaves. A sister project provides the means to read the sensors with RGB and hyperspectral cameras mounted on a robot. Together these provide a direct estimate of leaf wetness, which is closely tied to water stress. The density of sensor deployment is an open question although for noise reduction and redundancy it would be reasonable to have multiple sensors per tree. Research on non-contact sensing methods includes UGV platforms collecting NIR images and visible leaf spectra. In the longer run we expect that UAV and UGV platforms will eventually host imaging sensors developed in separate projects. In fact, byproducts of simultaneous mapping and localization research for autonomous UAV navigation under canopy are Lidar derived estimates of biomass and tree counts. Digital twins using tree growth models coupled with techniques from ML/AI are incorporated in the figure to create recommendations for drip irrigation. The spatio-temporal resolution required will likely model each individual tree and represent time at least by day and night increments. The growth model for an orchard tree is more complex than that for a corn plant but they are planted less densely and tree to tree interactions are less important than those for corn. Hence, the parallel computation may require fewer processing units per hectare than with corn.

University of California - Merced Testbed: The Merced testbed consists of two sites. The first site is an 8-acre pistachio orchard located south of Merced, California (37°15'58.99"N, 120°25'16.48"W) with eight-year-old trees. The second site is a private 22-acre almond orchard at North-West of Stevinson, California (37°21'17.53"N, 120°54'57.31"W). The trees are five years-old and the site has some variability in soil type. The Pistachio site already has internet coverage. We augmented the infrastructure through software and hardware for Wi-Fi towers and data storage servers. The optimal size of the batteries and solar panels was calculated based on the energy requirement of each system. A structure was built to install sensors over the canopy of a pistachio tree to install a permanent spectrophotometer to collect spectral data continuously. Two ARABLE Mark 2 with solar sensors were also installed to monitor temperature, precipitation, pressure,

humidity, wind, vapor pressure deficit (VPD), dew point temperature, solar radiation, and other spectral measurements and send their data to the company's data server via cellular LTE-M & 2G. In addition, 18 leaf-level water stress sensors were developed and installed in the field to monitor water stress continuously.

Joint Op 3 on Integrated Systems to Mitigate Disease and Pests is implemented at the University of Florida. The initial focus will be detection and mitigation of diseases of peanuts. In Florida peanuts are grown in the panhandle to just south of Gainesville in the north-central part of the state. Florida is typically ranked as the third highest producer of peanuts in the US. The climate is well-suited to peanut cultivation with slightly higher average rainfall and a longer frost-free growing season than in the Midwest of the United States. Farmland values are comparable to those around Indiana, indicating the north Florida farming system's capacity to support costs associated with IoT technologies is similar to that of midwestern farming and substantially lower than that found in the Central Valley of California. Several plant diseases severely impact peanut production. Late leaf spot and early leaf spot are responsible for the greatest losses among peanut biotic diseases. In 2019 the peanut crops in Florida and Georgia were devastated by an outbreak of aflatoxin, a highly carcinogenic mycotoxin produced by fungi prevalent in the soils of warm and humid regions. The problem is endemic and costs the industry on the order of 100 million dollars per year. Mitigation depends critically upon early detection, which is an important focus of the UF's testbed and of Joint Op 3.

Figure 4D.25 depicts the relationships between IoT4Ag projects currently involved in Joint Op 3. Joint Op 3 integrates a suite of projects to facilitate early detection and mitigation of foliar diseases and aflatoxin contamination of peanut. The projects focus on monitoring and detection of important environmental variables and plant and disease features coupled with communication

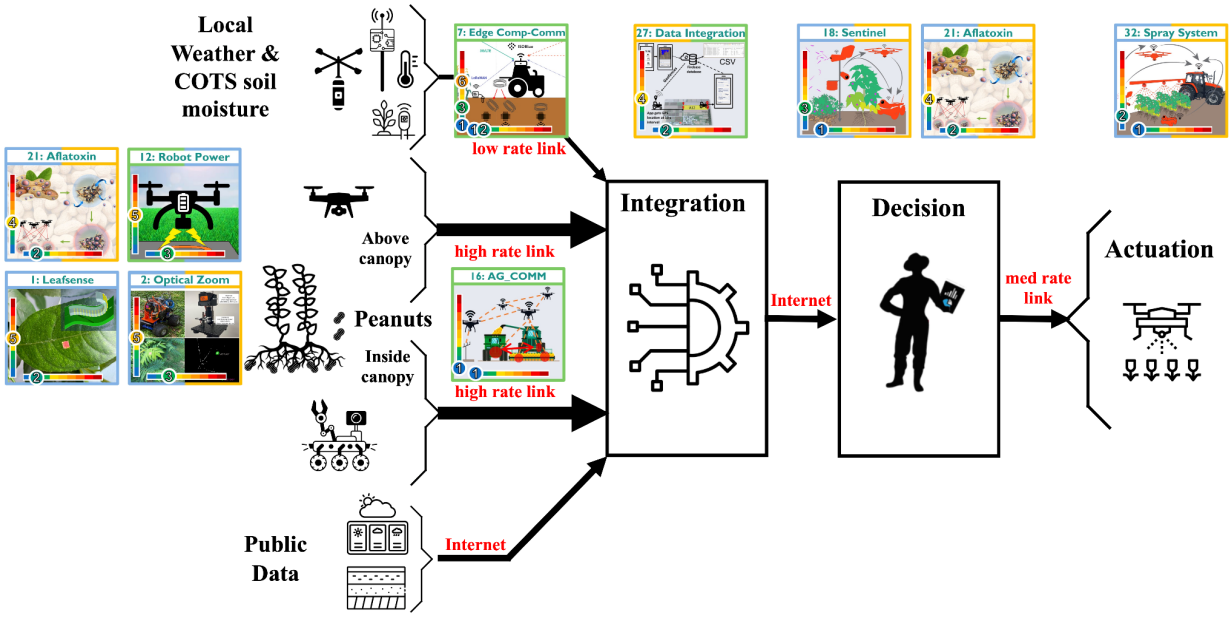


Figure 4D.25 Illustration of Joint Op 4 as data flows between IoT4Ag projects and integrations.

technologies and downstream analytics to inform decision-making and action. Other projects shown in the data flow diagram are independently developing ML methods for detecting aflatoxin from hyperspectral images of peanut pods and kernels. Joint Op 3 does not presently use crop growth models, so they are not included in the flow. Finally, a sprayer system project processes data from the sensor flows to treat diseased plants.

University of Florida Testbed: The IoT4Ag testbed environments in Florida are operational at the North Florida Research and Education Center (NFREC) locations in Live Oak and Quincy, FL. Testbed leads have been consulting with project leads to help inform design and development of IoT4Ag technologies. We are installing common LoRaWAN gateways across IoT4Ag testbed locations in Florida, Indiana, and California. This will facilitate opportunities for IoT4Ag researchers to easily connect their systems at any IoT4Ag test site. For the Florida testbed locations, we have acquired a Trimble RTK-GPS system that will enable cm-level corrections and highly accurate georeferencing for any projects testing systems that require these corrections. In partnership with industry member Agribugs we have obtained a waiver from the Federal Aviation Administration (FAA) for beyond visual line of sight (BVLOS) operations without an observer at the NFREC Quincy location. This is a major step forward for research and testing of autonomous UAS operations.

To support on-farm testing and deployment of IoT4Ag technologies, we engage with agricultural producers to plan for testing and demonstration. Engagement with these producers also provides an opportunity for the IoT4Ag center to learn about their perceptions and needs. Presentations on the IoT4Ag ERC and Testbed activities have been delivered to stakeholder groups at a symposium on sustainable cropping systems, the 2023 Beltwide Cotton Conference, and the Southern Peanut Growers Conference. In June 2023, we hosted a tour of Florida testbed facilities and equipment for IoT4Ag faculty, staff and students as part of the IoT4Ag annual retreat. Participants learned about agricultural production systems in Florida and the current state of precision agriculture technology. The visit provided IoT4Ag faculty, staff and students insight into the facilities, equipment and personnel available at the Florida testbed locations.

INPUTS & RESOURCES	ACTIVITIES	OUTPUTS	OUTCOMES		
			KNOWLEDGE SHORT-TERM	ACTION MEDIUM-TERM	IMPACTS LONG-TERM
•NSF funding and ERC program resources •Excellent faculty; undergraduate, graduate, and postdoctoral Fellows; and staff •State-of-the-art PI research laboratories and shared experimental and cloud and edge computing facilities •Existing and innovative science and technologies; data; and tools and methods from different disciplines •Campuses with row and tree crop control, plots, and field and orchard-scale instrumented testing facilities, representing the diversity of crops in the US •Agricultural extension programs to engage end-users •Scientific advisory board members •Existing and new relationships with industry members, government and innovation partners, and the end-user community of growers joining our industry practitioner and Ag-systems advisory boards	•Use and create IoT sensors for high-resolution, multi-mode sensing of plants / environment •Construct an autonomous robotic fleet to map targets in unstructured fields at scale •Design, fab, and test bio-degradable devices, e.g. batteries, sensors, antenna •Optimize waveforms for rural and agricultural communication •Investigate rapid recharging of and high-power density batteries •Generate robust, interoperable models for data of varying spatial and temporal resolution •Implement active learning for uncertainty reduction in agricultural situational awareness •Use massively parallel bio-physical models of fields/ orchards to constrain and train machine learning models and AI •Integrate all technologies in a system and evaluate in Joint Ops to engage industry and growers •Engage diverse end users on technology adoption	•Reliable, accurate, multi-mode sensor systems distributable at field scales for early detection of biotic/abiotic targets affecting crop yield and resiliency •Hardware-software tools for mapping and fusing chemical and physical data on targets above and below the soil surface •Ag-specific edge and backhaul communication technologies •Powers sources for field-scale deployment of sensors, robots •Data sets and software for use in research and adaptable to production for model development, training, calibration, or decision making •Digital twins for evaluating agricultural responses •Control, plot, and field testbed protocols for system evaluation •Cost-effective, integrated Ag sense-communication-response systems with AI and decision ag human-centered interfaces •Knowledge of socio-economic factors affecting precision Ag tech adoption	•Knowledge of technology requirements through guidance from our stakeholders composed of industry members, government and innovation partners, and growers •Disciplinarily diverse experts educate Center members and create new research and development opportunities •Advances in knowledge of plant, environmental, device, and data science and engineering •Creates innovative sensor, robotic, power, and communication technologies and new biophysically-constrained models, controls, and software interfaces to advance Ag practices •Produces publications, patent applications, copyrights, and new industry collaborations •Recognized as a global leader in sense-communication-response systems for agriculture, and commercial innovation through technology transfer	•Academia – government – industry partnership shortens the cycle to define-develop-deploy IoT4Ag systems •Increased number and types of measurable and interpretable plant and environmental targets, and increased areas and resolution in mapping •Higher data rate and longer-range communications with more coordinated robotic and farm machinery platforms; Ag-use case included in future communication standards •Better quality data for precision and scalable analytics and risk-aware interventions •Increased crop yield and quality from deployment of IoT4Ag systems, benchmarked against current industry methods •IoT4Ag builds on knowledge and technologies to receive additional funding from federal, state, philanthropic, or industry sources •Research yields new educational resources and tools	•Multidisciplinary Ag–Tech research is sustainable and growing, and broadens the impact of IoT in other sectors •Known best practice example of convergent research driving new knowledge and innovative technologies and systems for the benefit of society •Help realize the "NSF 10 Big Ideas" in Understanding the Rules of Life, Harnessing the Data Revolution, Mid-scale Research Infrastructure, and Growing Convergence Research •Deployed automated, integrated systems for early detection and intervention that transform agricultural practices •Increased efficiency of energy, water, and agrochemical use in farming establishing sustainable agricultural processes •Increased production of high-quality crops for greater US and global food security and higher profitability of farms •US is the global leader in precision agriculture

Figure 4D.26 Convergent Research Logic Model

ERCWEB TABLE 9: ESTIMATED BUDGETS BY RESEARCH THRUST

Estimated Budgets Table: Budgets by Research Thrust and Project Type				
Thrust	**Current Year Budget**			**Estimated Next Year Budget**
	Center Controlled Projects	**Sponsored Projects**	**Projects Total**	
Engineering Workforce Development	$252,129	$0	$252,129	$0
Thrust 1: Agricultural Sensors Systems	$2,868,186	$0	$2,868,186	$0
Thrust 2: Communication and Energy Systems	$1,295,221	$0	$1,295,221	$0
Thrust 3: Agricultural Response Systems	$964,796	$0	$964,796	$0

Table: Estimated Budgets by Research Thrust [1]						
Thrust	**Project Name**	**Organizational Sponsor**	**Project Leader**	**Investigators**	**Current Year Budget**	**Estimated Next Year Budget**
Engineering Workforce Development Thrust Leader: Sue Ann Bidstrup-Allen (University of Pennsylvania-Chemical and Biomolecular Engineering)	(34_STAKEHOLDER ENGAGEMENT) Community Engagement for Internet of Things for Precision Agriculture (IoT4Ag) NSF Engineering Research Cent (Center Controlled Project)	NSF ERC Program	Sebastian Galindo (University of Florida-Electrical and Computer Engineering)	Kathryn Stofer (University of Florida-Agricultural Education and Communication)	$252,129	$0
				Translational Research Projects Within Thrust	**$0**	
				Subtotal (all projects) for Thrust	**$252,129**	**$0**
				Total Number of Undergraduate Students in Thrust	**0**	
				Total Number of Graduate Students (M.S. and Ph.D.) in Thrust	**2**	
				Total Number of Postdocs in Thrust	**0**	
				Total Number of Personnel in Thrust	**5**	
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)	(01_LEAFSENSE) Leaf Moisture and Temperature Sensors (Center Controlled Project)	NSF ERC Program	Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering)	Paulo Arratia (University of Pennsylvania-Mechanical Engineering & Applied Mechanics) Reza Ehsani (University of California, Merced-Mechanical Engineering) Ian M. Small (University of Florida-Plant Pathology) Kevin T. Turner (University of Pennsylvania-Mechanical Engineering and Applied Mechanics) Tony J. Vyn (Purdue University-Agronomy)	$299,438	$0

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)	(02_OPTICAL ZOOM) Sensor and Detector (Center Controlled Project)	NSF ERC Program	Sanjeev Koppal (University of Florida-Electrical and Computer Engineering)	David J. Cappelleri (Purdue University-Mechanical Engineering) Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	$121,272	$0
	(03_SUBSURFACE SENSE) Passive, Sub-Surface Biodegradable Sensors and Components (Center Controlled Project)	NSF ERC Program	Troy Olsson (University of Pennsylvania-Electrical and Systems Engineering)	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering) Paulo Arratia (University of Pennsylvania-Mechanical Engineering & Applied Mechanics) Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Ian M. Small (University of Florida-Plant Pathology) Kevin T. Turner (University of Pennsylvania-Mechanical Engineering and Applied Mechanics)	$645,218	
	(04_AIR BATTERIES) Biodegradable Air Batteries for Distributed Sensing (Center Controlled Project)	NSF ERC Program	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering)	Troy Olsson (University of Pennsylvania-Electrical and Systems Engineering)	$6,144	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)	(04_AIR BATTERIES) Biodegradable Air Batteries for Distributed Sensing (Center Controlled Project)	NSF ERC Program	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering)	Tony J. Vyn (Purdue University-Agronomy)	$6,144	$0
	(08_AGBOT) AgBot – Corn-Sampling Unmanned Ground Vehicle (UGV) (Center Controlled Project)	NSF ERC Program	David J. Cappelleri (Purdue University-Mechanical Engineering)	Melba Crawford (Purdue University-Civil Engineering) James Krogmeier (Purdue University-Electrical and Computer Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science) Daniel Quinn (Purdue University-Agriculture and Natural Resources) Tony J. Vyn (Purdue University-Agronomy)	$233,309	
	(09_SEMANTIC MAPPING) Semantic Mapping of Orchards for Yield Estimation (Center Controlled Project)	NSF ERC Program	Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	David J. Cappelleri (Purdue University-Mechanical Engineering) Pratik Chaudhari (University of Pennsylvania-Electrical and Systems Engineering) Reza Ehsani (University of California, Merced-Mechanical Engineering)	$365,847	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)	(10_PATH PLANNING) Informed Path Planning for Data Collection in Orchards (Center Controlled Project)	NSF ERC Program	Stefano Carpin (University of California, Merced-Computer Science and Engineering)	Reza Ehsani (University of California, Merced-Mechanical Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	$120,175	$0
	(12_ROBOT POWER) Autonomous Wireless Charging of Drones (Center Controlled Project)	NSF ERC Program	Sue Ann Bidstrup-Allen (University of Pennsylvania-Chemical and Biomolecular Engineering)	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering) David P. Arnold (University of Florida-Electrical and Computer Engineering)	$621	
	(17_ORCHARD) Developing Technology for Detecting Tree-Specific Water Stress in an Orchard (Center Controlled Project)	NSF ERC Program	Reza Ehsani (University of California, Merced-Mechanical Engineering)	Stefano Carpin (University of California, Merced-Computer Science and Engineering)	$164,691	
	(18_SENTINEL) Sentinel: Sensor-based field scouting and plant health monitoring system (Center Controlled Project)	NSF ERC Program	Ian M. Small (University of Florida-Plant Pathology)	David P. Arnold (University of Florida-Electrical and Computer Engineering) David J. Cappelleri (Purdue University-Mechanical Engineering) William Eisenstadt (University of Florida-Electrical and Computer Engineering) Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering)	$199,192	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)	(18_SENTINEL) Sentinel: Sensor-based field scouting and plant health monitoring system (Center Controlled Project)	NSF ERC Program	Ian M. Small (University of Florida-Plant Pathology)	Alina Zare (University of Florida-Electrical and Computer Engineering)	$199,192	$0
	(19_FLOWERING) Monitoring Flowering of Row Crops via High-Resolution Remote Sensing Platforms (Center Controlled Project)	NSF ERC Program	Melba Crawford (Purdue University-Civil Engineering)	David J. Cappelleri (Purdue University-Mechanical Engineering)	$72,866	
	(20_CORN MASS & N2) Corn Phenology, Biomass, and Nitrogen Efficiency Prediction from Integrated Sensors (Center Controlled Project)	NSF ERC Program	Melba Crawford (Purdue University-Civil Engineering)	Daniel Quinn (Purdue University-Agriculture and Natural Resources)	$104,176	
	(21_AFLATOXIN) Assessing Aflatoxin risk points in Peanuts (Center Controlled Project)	NSF ERC Program	Brent Sumerlin (University of Florida-Chemistry)	Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Alina Zare (University of Florida-Electrical and Computer Engineering)	$176,623	
	(22_DATA FUSION) Multi-Resolution Raster Data Collection (Center Controlled Project)	NSF ERC Program	Erin Hestir (University of California, Merced-Civil & Environmental Engineering)	Stefano Carpin (University of California, Merced-Computer Science and Engineering) Melba Crawford (Purdue University-Civil Engineering) Reza Ehsani (University of California, Merced-Mechanical Engineering)	$677	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)	(22_DATA FUSION) Multi-Resolution Raster Data Collection (Center Controlled Project)	NSF ERC Program	Erin Hestir (University of California, Merced-Civil & Environmental Engineering)	Alina Zare (University of Florida-Electrical and Computer Engineering)	$677	$0
	(24_BIOPHYSICS) Biophysical Model Enablement (Center Controlled Project)	NSF ERC Program	Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	James Krogmeier (Purdue University-Electrical and Computer Engineering) Daniel Quinn (Purdue University-Agriculture and Natural Resources)	$50,501	
	(29_ROBOT COMM) Deployment of Autonomous Ground Robots to Facilitate Communication (Center Controlled Project)	NSF ERC Program	Alejandro Ribeiro (University of Pennsylvania-Electrical and System Engineering)	David J. Cappelleri (Purdue University-Mechanical Engineering) Stefano Carpin (University of California, Merced-Computer Science and Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	$6,998	
	(32_SPRAY SYS) Improving the Efficiency of Crop Input Applications Using Advanced Spray Systems (Center Controlled Project)	NSF ERC Program	Ian M. Small (University of Florida-Plant Pathology)	William Eisenstadt (University of Florida-Electrical and Computer Engineering) Alina Zare (University of Florida-Electrical and Computer Engineering)	$166,637	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 1: Agricultural Sensors Systems Thrust Leader: Reza Ehsani (University of California, Merced-Mechanical Engineering)\	(33_NUTRIENT MANAGEMENT) A new paradigm for nutrient management in the US enabled by sensing, IoT and prediction modeling (Center Controlled Project)	NSF ERC Program	Carlos Messina (University of Florida-Horticultural Sciences)	Melba Crawford (Purdue University-Civil Engineering) Vivek Sharma (University of Florida-Agricultural and Biological Engineering)	$79,462	$0
				Translational Research Projects Within Thrust	**$0**	
				Subtotal (all projects) for Thrust	**$2,813,847**	**$0**
				Total Number of Undergraduate Students in Thrust	**28**	
				Total Number of Graduate Students (M.S. and Ph.D.) in Thrust	**53**	
				Total Number of Postdocs in Thrust	**7**	
				Total Number of Personnel in Thrust	**121**	
Thrust 2: Communication and Energy Systems Thrust Leader: Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering)	(03_SUBSURFACE SENSE) Passive, Sub-Surface Biodegradable Sensors and Components (Center Controlled Project)	NSF ERC Program	Troy Olsson (University of Pennsylvania-Electrical and Systems Engineering)	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering) Paulo Arratia (University of Pennsylvania-Mechanical Engineering & Applied Mechanics) Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Ian M. Small (University of Florida-Plant Pathology) Kevin T. Turner (University of Pennsylvania-Mechanical Engineering and Applied Mechanics)	$105,122	$0

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 2: Communication and Energy Systems Thrust Leader: Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering)	(04_AIR BATTERIES) Biodegradable Air Batteries for Distributed Sensing (Center Controlled Project)	NSF ERC Program	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering)	Troy Olsson (University of Pennsylvania-Electrical and Systems Engineering) Tony J. Vyn (Purdue University-Agronomy)	$116,726	$0
	(07_EDGE COMP_COMM) Edge Computing and Communication for Agricultural Sensors (Center Controlled Project)	NSF ERC Program	James Krogmeier (Purdue University-Electrical and Computer Engineering)	Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering) David J. Love (Purdue University-Electrical and Computing Engineering)	$261,911	
	(08_AGBOT) AgBot – Corn-Sampling Unmanned Ground Vehicle (UGV) (Center Controlled Project)	NSF ERC Program	David J. Cappelleri (Purdue University-Mechanical Engineering)	Melba Crawford (Purdue University-Civil Engineering) James Krogmeier (Purdue University-Electrical and Computer Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science) Daniel Quinn (Purdue University-Agriculture and Natural Resources) Tony J. Vyn (Purdue University-Agronomy)	$25,923	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 2: Communication and Energy Systems Thrust Leader: Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering)	(11_CLUTTERED ENVIRONMENTS) Wireless Charging of Electronics in Cluttered Environments (Center Controlled Project)	NSF ERC Program	David P. Arnold (University of Florida-Electrical and Computer Engineering)	William Eisenstadt (University of Florida-Electrical and Computer Engineering)	$127,790	$0
	(12_ROBOT POWER) Autonomous Wireless Charging of Drones (Center Controlled Project)	NSF ERC Program	Sue Ann Bidstrup-Allen (University of Pennsylvania-Chemical and Biomolecular Engineering)	Mark G. Allen (University of Pennsylvania-Electrical and Systems Engineering) David P. Arnold (University of Florida-Electrical and Computer Engineering)	$240,771	
	(16_AG COMM) Communication to Enable Agricultural Sensing (Center Controlled Project)	NSF ERC Program	David J. Love (Purdue University-Electrical and Computing Engineering)	David P. Arnold (University of Florida-Electrical and Computer Engineering) Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering) William Eisenstadt (University of Florida-Electrical and Computer Engineering) James Krogmeier (Purdue University-Electrical and Computer Engineering) Ian M. Small (University of Florida-Plant Pathology)	$241,920	
	(27_DATA INTEGRATION) Data Interoperability and Integration (Center Controlled Project)	NSF ERC Program	Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	James Krogmeier (Purdue University-Electrical and Computer Engineering)	$50,501	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
	(29_ROBOT COMM) Deployment of Autonomous Ground Robots to Facilitate Communication (Center Controlled Project)	NSF ERC Program	Alejandro Ribeiro (University of Pennsylvania-Electrical and System Engineering)	David J. Cappelleri (Purdue University-Mechanical Engineering) Stefano Carpin (University of California, Merced-Computer Science and Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	$124,557	
Translational Research Projects Within Thrust					**$0**	
Subtotal (all projects) for Thrust					**$1,295,221**	**$0**
Total Number of Undergraduate Students in Thrust					**12**	
Total Number of Graduate Students (M.S. and Ph.D.) in Thrust					**27**	
Total Number of Postdocs in Thrust					**3**	
Total Number of Personnel in Thrust					**62**	
Thrust 3: Agricultural Response Systems Thrust Leader: Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	(02_OPTICAL ZOOM) Sensor and Detector (Center Controlled Project)	NSF ERC Program	Sanjeev Koppal (University of Florida-Electrical and Computer Engineering)	David J. Cappelleri (Purdue University-Mechanical Engineering) Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	$54,339	$0
	(09_SEMANTIC MAPPING) Semantic Mapping of Orchards for Yield Estimation (Center Controlled Project)	NSF ERC Program	Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	David J. Cappelleri (Purdue University-Mechanical Engineering)	$40,650	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 3: Agricultural Response Systems Thrust Leader: Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	(09_SEMANTIC MAPPING) Semantic Mapping of Orchards for Yield Estimation (Center Controlled Project)	NSF ERC Program	Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	Pratik Chaudhari (University of Pennsylvania-Electrical and Systems Engineering) Reza Ehsani (University of California, Merced-Mechanical Engineering)	$40,650	$0
	(10_PATH PLANNING) Informed Path Planning for Data Collection in Orchards (Center Controlled Project)	NSF ERC Program	Stefano Carpin (University of California, Merced-Computer Science and Engineering)	Reza Ehsani (University of California, Merced-Mechanical Engineering) Vijay Kumar (University of Pennsylvania-Engineering and Applied Science)	$13,353	
	(16_AG COMM) Communication to Enable Agricultural Sensing (Center Controlled Project)	NSF ERC Program	David J. Love (Purdue University-Electrical and Computing Engineering)	David P. Arnold (University of Florida-Electrical and Computer Engineering) Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering) William Eisenstadt (University of Florida-Electrical and Computer Engineering) James Krogmeier (Purdue University-Electrical and Computer Engineering) Ian M. Small (University of Florida-Plant Pathology)	$26,880	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 3: Agricultural Response Systems Thrust Leader: Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	(17_ORCHARD) Developing Technology for Detecting Tree-Specific Water Stress in an Orchard (Center Controlled Project)	NSF ERC Program	Reza Ehsani (University of California, Merced-Mechanical Engineering)	Stefano Carpin (University of California, Merced-Computer Science and Engineering)	$18,299	$0
	(18_SENTINEL) Sentinel: Sensor-based field scouting and plant health monitoring system (Center Controlled Project)	NSF ERC Program	Ian M. Small (University of Florida-Plant Pathology)	David P. Arnold (University of Florida-Electrical and Computer Engineering) David J. Cappelleri (Purdue University-Mechanical Engineering) William Eisenstadt (University of Florida-Electrical and Computer Engineering) Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Alina Zare (University of Florida-Electrical and Computer Engineering)	$35,681	
	(19_FLOWERING) Monitoring Flowering of Row Crops via High-Resolution Remote Sensing Platforms (Center Controlled Project)	NSF ERC Program	Melba Crawford (Purdue University-Civil Engineering)	David J. Cappelleri (Purdue University-Mechanical Engineering)	$20,435	
	(20_CORN MASS & N2) Corn Phenology, Biomass, and Nitrogen Efficiency Prediction from Integrated Sensors (Center Controlled Project)	NSF ERC Program	Melba Crawford (Purdue University-Civil Engineering)	Daniel Quinn (Purdue University-Agriculture and Natural Resources)	$11,575	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 3: Agricultural Response Systems Thrust Leader: Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	(21_AFLATOXIN) Assessing Aflatoxin risk points in Peanuts (Center Controlled Project)	NSF ERC Program	Brent Sumerlin (University of Florida-Chemistry)	Cherie Kagan (University of Pennsylvania-Electrical and Systems Engineering) Alina Zare (University of Florida-Electrical and Computer Engineering)	$19,625	$0
	(22_DATA FUSION) Multi-Resolution Raster Data Collection (Center Controlled Project)	NSF ERC Program	Erin Hestir (University of California, Merced-Civil & Environmental Engineering)	Stefano Carpin (University of California, Merced-Computer Science and Engineering) Melba Crawford (Purdue University-Civil Engineering) Reza Ehsani (University of California, Merced-Mechanical Engineering) Alina Zare (University of Florida-Electrical and Computer Engineering)	$158,107	
	(24_BIOPHYSICS) Biophysical Model Enablement (Center Controlled Project)	NSF ERC Program	Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	James Krogmeier (Purdue University-Electrical and Computer Engineering) Daniel Quinn (Purdue University-Agriculture and Natural Resources)	$97,069	
	(27_DATA INTEGRATION) Data Interoperability and Integration (Center Controlled Project)	NSF ERC Program	Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	James Krogmeier (Purdue University-Electrical and Computer Engineering)	$97,069	

Thrust	Project Name	Organizational Sponsor	Project Leader	Investigators	Current Year Budget	Estimated Next Year Budget
Thrust 3: Agricultural Response Systems Thrust Leader: Dennis R. Buckmaster (Purdue University-Agricultural & Biological Engineering)	(28_TECH ADOPTION) Barriers to Adopting IoT4Ag Technology: Mixed Methods Research Study (Center Controlled Project)	NSF ERC Program	Melanie L. Yeo (University of California, Merced-Management of Complex Systems)	Sebastian Galindo (University of Florida-Electrical and Computer Engineering) Catherine Keske (University of California, Merced-Management, Innovation, Sustainability, Technology) Kathryn Stofer (University of Florida-Agricultural Education and Communication)	$154,879	$0
	(32_SPRAY SYS) Improving the Efficiency of Crop Input Applications Using Advanced Spray Systems (Center Controlled Project)	NSF ERC Program	Ian M. Small (University of Florida-Plant Pathology)	William Eisenstadt (University of Florida-Electrical and Computer Engineering) Alina Zare (University of Florida-Electrical and Computer Engineering)	$58,931	
	(33_NUTRIENT MANAGEMENT) A new paradigm for nutrient management in the US enabled by sensing, IoT and prediction modeling (Center Controlled Project)	NSF ERC Program	Carlos Messina (University of Florida-Horticultural Sciences)	Melba Crawford (Purdue University-Civil Engineering) Vivek Sharma (University of Florida-Agricultural and Biological Engineering)	$212,243	
Translational Research Projects Within Thrust					**$0**	
Subtotal (all projects) for Thrust					**$1,019,135**	**$0**
Total Number of Undergraduate Students in Thrust					**14**	
Total Number of Graduate Students (M.S. and Ph.D.) in Thrust					**44**	
Total Number of Postdocs in Thrust					**5**	
Total Number of Personnel in Thrust					**92**	

[1] The sum of personnel for all thrusts may be greater than the total number of personnel associated with the ERC if personnel are associated with projects under multiple thrusts.

[2] Starting in 2023, Associated Project details are not included in this table and are instead reflected in the separate Associated Projects reporting table.

4E. ENGINEERING WORKFORCE DEVELOPMENT

SUMMARY OF GOALS & ACCOMPLISHMENTS

Goals: IoT4Ag aims to a) **Excite** youth and public audiences about STEM and agriculture through fun and engaging activities and by connecting agricultural and physical science and engineering to solutions that benefit society and to the IoT4Ag vision; b) **Educate** college/university students and postdocs and prepare them for rewarding and impactful agriculture and STEM careers in an inclusive world; and c) **Enable** early to established growers and engineering and agriculture professionals to advance their careers and to accelerate their practice, and/or pedagogy, of Ag-Tech systems. The **IoT4Ag Empowering People Portfolio: Excite-Educate-Enable (IoT4Ag E^3)** is designed to "**grow people**" and **catalyze systemic change** in agricultural and educational practice (**Fig. 4E.1, bottom**).

IoT4Ag E^3 Overview and **Structure**: We cultivate the **IoT4Ag E^3 Portfolio to be diverse** and manage it **to encourage innovation**. Activities fall along continuums of **uniqueness**, **readiness**, and anticipated **lifespan**. Some programs are widely established, best-practice programs (REU, RET), while our "Signature Initiatives" are more unique deployments of evidence-based EWD- and DCI-related strategies. Some programs now require creative scaling while others are in early conceptual or piloting stages. Anticipated lifespans of our activities range from participation in events that are aligned with IoT4Ag E^3 goals and/or support IoT4Ag partnership building to Center-led programs that are strong candidates for sustainability beyond NSF ERC funding. Because we **manage the portfolio for innovation**, we also embrace that this testbed approach comes with risk AND potential for **identifying** and **investing** in the most **impactful IoT4Ag E^3 activities and programs** to **EXCITE**, **EDUCATE**, and **ENABLE people** to **grow their own academic** and **career aspirations** and to **accelerate** progress towards **food**, **energy**, and **water security** for the **planet's people** and for **sustainable, functioning ecosystems**.

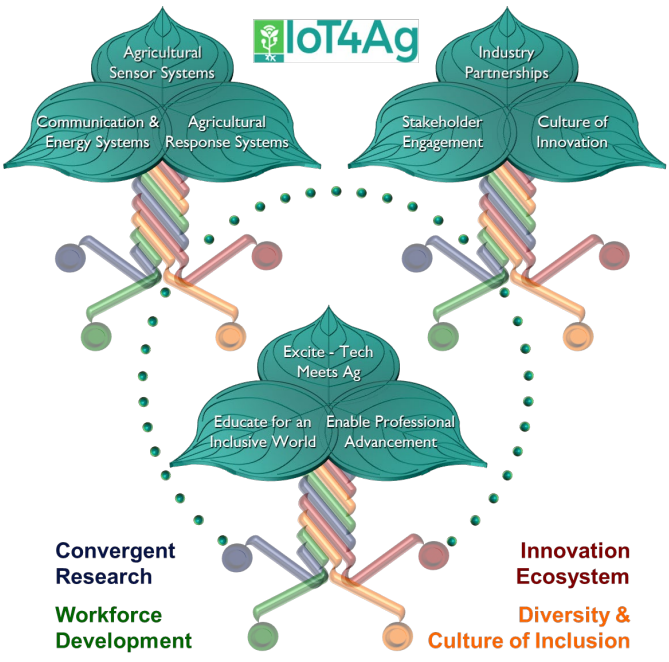


Figure 4E.1 Summary of integrated IoT4Ag thrusts and programmatic axes and their relationship to the four NSF Gen-4 ERC Foundational Components.

Engineering workforce development (EWD) functions synergistically with IoT4Ag's other foundational components (Convergent Research, Innovation Ecosystem and Diversity & Culture of Inclusion (DCI)) to deliver on the Center's strategic plan, and ultimately, the Center's vision and mission (**Fig. 4E.1**). The EWD and DCI foundational components are described in separate sections of this report but are inseparable. For *all* foundational components, the Center community puts into practice the vision that **agriculture** and **STEM academic, research,** and **career paths** are **exciting**, **welcoming**, and **full of opportunity**.

For EWD and DCI, each foundational component takes the lead on specific

programs. There are dedicated joint meetings to take advantage of everyone's expertise. This fosters collaboration to deliver programming that is effective for the intended EWD audiences and is consistent with valuing diversity and inclusion in academic and professional environments. Similarly, our external Advisory Board members with expertise spanning EWD and DCI topics now operate, meeting and providing guidance, as a single board.

Key Accomplishments:

- Launch of **IoT4Ag E^3**
  - Accomplishment: In Year 4, **IoT4Ag E^3** was rolled out with the addition of a new position, Director of Education and Inclusivity, Dr. Kristin Field, charged with strategic integration and implementation of IoT4Ag's EWD and DCI programs.
  - Impact: IoT4Ag has a clearly communicated, cohesive vision and executable plan for EWD and DCI programs, identified as a priority by our Advisory Board members and most recent site visit team.
- **EXCITE** – Tech Meets Ag
  - Accomplishments:
    - In Year 4, 13 K-12 outreach events across and beyond the regions of IoT4Ag's campuses use the robot and sensor kits and curriculum developed in Years 1 through 3, engaging over 900 attendees.
    - Curriculum deployment of IoT4Ag modules for 6-week summer camp for 48 middle school students from a Latino-focused Community-Based Organization.
    - Accelerated classroom reach with continued teacher engagement with 4 new teachers in the 2024 RET cohort, plus teachers from earlier cohorts using the IoT4Ag- and Ag-Tech-related content from their 2022 and 2023 RET summers.
  - Impact: IoT4Ag EXCITE is engaging with youth and public audiences in formal and informal learning environments about cutting edge technology creating "farms of the future" and about the opportunities that STEM and agriculture career paths allow for securing food, energy, and water security. Growing the number of partnering teachers magnifies the number of youth affected and paves the way for longer term impact on educational systems.
- **EDUCATE** for an Inclusive World
  - Accomplishments:
    - 24 postdoctoral fellows, 91 graduate students (79% (N=72) PhD-level) and 73 undergraduates contributing to and learning from IoT4Ag research since the Center launched in 2020.
    - 17 trainee-exchanges accelerated research collaborations and cross-institutional community building since the Intra-ERC Technical Exchange (ITEX) Program started in Year 3 (8 exchanges in Year 4).
    - 28 summer REU undergraduate researchers hosted and trained by IoT4Ag during the Year 4 reporting period (May-August 2023=13; May-August 2024=15); 4 of the REU students came from a predominantly associate's degree institution/community college.
    - 30 undergraduates participated in 9 IoT4Ag-themed capstone design projects (Year 4).
  - Impact: IoT4Ag EDUCATE provides unique convergent research and IoT4Ag-infused course-based opportunities for 2-year college students through postdoctoral researchers;

the Center EDUCATE summer research and course participants, and its longer research-based graduates (17 Bachelor's, 11 Master's and 20 PhD degrees awarded, 37 papers co-authored with students) bring their multifaceted ERC training to their next academic and career stages.

- **ENABLE** Professional Advancement
  - Accomplishments:
    - Delivery of 15 invited or guest lectures and/or presentations at professional conferences, events, extension facilities, and workshops.
    - IoT4Ag exhibits, including the NTCA Fall Conference on Forging the Future of Rural Broadband, the World Ag Expo 2024 (100,000+ attendees representing 49 states, District of Columbia, and 81 countries), SW Florida Precision Agriculture Technology Expo 2024, and Southeast Purdue Ag Center Field Day.
    - 2 IoT4Ag social scientist-led research projects on tech adoption and end-user engagement and trust-building.
  - Impacts: IoT4Ag ENABLE established a comprehensive, science-based approach to stakeholder engagement. Through Center engagement activities with the end-use grower community (producers, crop consultants, associations, extension agents), IoT4Ag is sharing knowledge and resources that can help advance the careers of individuals, and is listening, responding, and building trusted relationships key to successful IoT4Ag technology and system adoption.

Below we describe the **IoT4Ag E^3** portfolio but pull out REU and RET programs to be consistent with the NSF report structure.

IOT4AG EDUCATE: RESEARCH EXPERIENCES FOR UNDERGRADUATES (REU)

The REU is a **best-practice, core** program in **IoT4Ag EDUCATE**. The summer REU provides 2- and 4-year college students mentored, collaborative experiences on IoT4Ag Convergence Research projects. Projects can meaningfully accelerate progress on the Center's research thrust goals. Over this reporting period, IoT4Ag hosted 13 REU students in 2023 and 15 in 2024; the program runs May-August each year. We detailed the 2023 cohort in the Year 3 report and will focus on the 2024 cohort here.

Components and Training: Every year IoT4Ag REU students participate in the Center Annual Retreat. In advance of the Retreat, we ran **cross-institutional programming** including an REU *Welcome* with IoT4Ag Director, C. Kagan (May 31, 2024) and an REU *What is Networking* session (K. Field, June 17, 2024). These sessions help orient REU participants, since most have had little experience with being part of a large, multi-institution Center, and prepare students for the upcoming in-person Center-wide **Boot Camp** and **Retreat**. Once again REU students joined the Center in traveling to the Boot Camp and Retreat, this year at UC Merced. Students interacted with the whole Center, giving them a more holistic feel for **IoT4Ag culture** and, more broadly, an **early**, **immersive experience** in a friendly and **professional research and innovation environment**. At the Boot Camp, the **REU-breakout session** icebreaker (**Fig. 4E.2a**) and

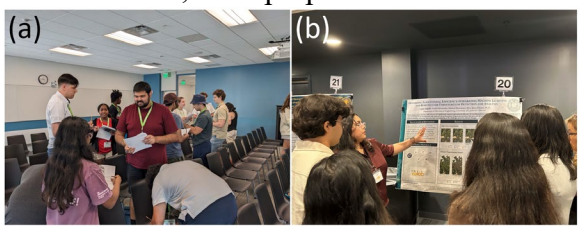


Figure 4E.2 (a) REU Cohort 2024 at Boot Camp icebreaker at UC Merced. (b) Merced College REU Student at UC Merced poster session presenting her summer research.

team-building Retreat-themed scavenger hunt continued to support the students' interactions with each other and with the more senior Center members (i.e., graduate students to faculty to professionals participating as speakers or in their advisory board capacities).

REU students completed required online Collaborative Institutional Training Initiative (CITI) modules for **ethical conduct of research** and host institution laboratory safety training. Campuses provided local programming for their REU students, including research talks, professional development sessions (e.g., skills-based how-to workshops on topics including literature reviews, time management, technical presentations, entrepreneurship/intellectual property, graduate school and a brief overview of the NSF Graduate Research Fellowship Program) and opportunities for student summer research presentations (**Fig. 4E.2b**).

REU Participants: The 2024 cohort included 6 students (40%) who identify as women, 8 (53%) as men, and 1 who chose not to report gender. 9 students (60%) reported being non-white or multi-racial; 5 reported being white, and 1 chose not to report race. 4 of the 15 (27%) identified as Hispanic or Latino. Six (6) students were funded partially or in full by core partner university resources. REU home institutions without R1 or R2 research intensity designation and/or with Minority Serving Institution designation are indicated in **Appendix Table 4E.1**. 3 participants were from community colleges. IoT4Ag also stays in touch with our REU alums and tracks their career progressions; 2 are NSF Graduate Research Fellowships Program Awardees (**Appendix Table 4E.2**).

IOT4AG EXCITE: RESEARCH EXPERIENCES FOR TEACHERS (RET)

The RET is a **best-practice, core** program in **IoT4Ag EXCITE**. The Penn-based RET is designed to connect pre-college educators and K-12 schools with IoT4Ag. Involving K-12 teachers with the Center's research and education communities creates opportunities to communicate the urgency of the societal grand challenge of food, energy, and water security and the relevance of Ag and STEM career paths for addressing this grand challenge. The RET focuses on **developing lesson plans** and **curricular activities** around the intersections of **technology** and **agriculture** and their related **science** and **engineering** topics. IoT4Ag EXCITE provides support for teachers to develop **high quality content** to share with their students and to **disseminate** on online platforms for home school learners, educators, and administrators globally. For the RET participants, we intend for the program to **support** the **educators'** own **career aspirations**, consistent with **IoT4Ag ENABLE**.

Components and Training: In 2022 and 2023, teachers were hosted by IoT4Ag research groups and divided their time between lab projects, mentored by host faculty and trainees, and developing teaching activities and demos focused on micro:bit processors for robot path planning, soil moisture sensing and monitoring, and control of robotic watering systems, as well as on the development of organic batteries. In 2024, we tried something new to facilitate greater cohort-building among the teachers and to enable a peer-support system for implementation of IoT4Ag-related materials at their schools. We brought in pairs of teachers who shared the same school. We exposed them to the breadth of IoT4Ag convergence research through talks and discussion (not hosted by more focused individual research groups). The 2024 teachers shared a communal office and worked on teaching activities together for their classes and/or for extracurricular student clubs. This iterative process of assessment, exploration, and innovation in structure and implementation of our programs runs through IoT4Ag E^3 to reach our intended outcomes efficiently and well.

RET Participants: 2023 was IoT4Ag's 2nd RET cohort; this reporting period overlaps with the start of the 3rd cohort (June 17 - August 8, 2024). Cohorts are selected for the teacher's and their

school's potential to reach students who may not have as much exposure to STEM and/or to leverage schools where students have already identified interests in agriculture or environmental sciences (RET participants, School Demographics listed in **Appendix Table 4E.3**).

Enabling continuity and fostering impact: All cohorts have participated in designing and leading some of the ACLAMO camp activities (described below in the **IoT4Ag EXCITE section**) and have built on previous lessons using Smart Cutebots. RET teachers have access to funds for materials for IoT4Ag activities that they bring back to their schools. RET alums from 2022 and 2023 shared ways in which they have integrated aspects of their IoT4Ag experience at their home institutions (**Below,** and **Fig. 4E.3**).



Figure 4E.3 Students at Alain Locke Elementary School working in the (a) mini farm and (b) lessons with the Cutebots.

<u>Updates from RET alums</u> (excerpts from correspondence collected in Spring-Summer 2024**;** schools located in Philadelphia unless noted otherwise)

<u>2022 Cohort</u>

R. Buckley (Alain Locke Elementary): *Almost all my students have never experienced anything remotely related to agriculture. [Spring 2023]….I ran a robotics club using the Cutebots that we used during the summer RET program. I also started a mini farm with the stipend from Penn at my school. Both the garden and robotics are starting up again [in Spring 2024].*

K. Hassey (moved to Truman HS, Levittown PA): *I am teaching Business now. I am also facilitating a Women in Engineering and their Allies / girls who code club after school. Last year we used the Cutebots and micro:bits during freshman takeover day, in the after school club and during family STEM night at the local middle school. There are a ton of opportunities for my club students through the IOT4ag….*

B. Washington (Hamilton West HS, Hamilton NJ): *My high school was able to implement the lesson plan within our robotics class. It was a great introductory level lesson that also exposed them to aspects of agriculture. Additionally, we used the lesson within our engineering class as well! Lastly, it's a lesson I provide through my nonprofit organization, The STREAM Engine. We're currently in the process of establishing a new cohort of students to provide instruction.*

R. Zimny (Julia R. Masterman School): *….Since Bio is a tested subject, there is a ton of content to get through. I was able to use the materials that IoT4Ag provided for me to put together a "Smart" Fish Tank with a small Aquaponics system. I had some of my Seniors… get the tank running. They used the experience as part of their community service hours for their Senior/Graduation project. ….I'm also planning on working on incorporating the tank into some of my lessons this year & next year about matter cycles & energy transfers in an ecosystem…. I can definitely see that having a serious agricultural focus that I will cycle back to throughout the unit.*

<u>2023 Cohort</u>

E. Cruz (Kensington HS): *This project inspired me to write a grant to get a class set of drones. It was approved! ….My ideas have remained the same since my RET final presentation: Mini Farm, Maintain and grow healthy plants and track data, Build an LED array to help plants grow, Drone Technology, Design and 3D print or laser-cut drone parts and build a custom drone, Simulate dropping seeds into the mini-farm, Drop seed bombs in the neighborhood, Industry and*

Community Outreach, Task students to interview a farmer, Task students to meet engineers working in agriculture fields, Drone Flight Certification (meets grad requirements)….

J. Turko (Walter B. Saul HS of Agricultural Sciences): *I am currently working on two major systems for implementing engineering into agriculture: a club and lessons….I am running an agriscience and technology club which has roughly about 10 members. During this time, I have covered the basics of robotics, coding and how it can be integrated into agriculture. I utilized the programming of Cutebots…and had students program Cutebots to follow lines…we will be moving on to more complicated applications. For the classroom, I am currently working on making lessons and worksheets for teachers. They allow for flexibility so that any teacher in any ag study can utilize them.*

ERC PARTICIPANT ENGAGEMENT

IoT4Ag is engaging participants through its **IoT4Ag Empowering People Portfolio: Excite-Educate-Enable** (**IoT4Ag E^3**). Here we describe highlights from across the Center.

EXCITE - Tech Meets Ag: As a practice, the IoT4Ag community prepares and delivers EXCITE demos and activities to be **appropriate** for **specific audiences** and **forums**. The tailoring and delivery of activities leverage the **local strengths** and **partners** of the IoT4Ag site or team leading the activity. The IoT4Ag faculty, postdoc, graduate students, and staff who organize, design, and deliver activities are key for EXCITE implementation. They bring their **pedagogical**, **research,** and **entrepreneurial expertise** to the events and programs. When the EXCITE audiences are new to STEM, the IoT4Ag teams make "engineer," "scientist," "researcher" and "student" labels real and accessible. These interactions also provide Center members with opportunities for personal and professional development (and satisfaction!).

One of IoT4Ag's **Signature Initiatives** is the creation of adaptable lesson plans, activities, and curriculum around coding, sensing, robotics, data, computer systems, and technology for farming and food, water, and energy security in a changing world. **Smart Cutebot Kits** are a **powerful hands-on** component of many of these EXCITE **lesson plans** and **curricula**, which can be used in formal and informal settings and adapted for the learners' backgrounds, interests, and educational levels. They have been used to excite youth in camps, workshops, conferences, and schools (more details in the **RET section**). They have been deployed at our DCI-led sessions at Junior MANRRS (National Society for Minorities in Agriculture, Natural Resources and Related Sciences; see **4F. Diversity & Culture of Inclusion** section). EXCITE engagement also centers around **demonstrations** related to IoT4Ag's **convergent research** and **real-world applications** of **Ag-Tech** (e.g., showing and answering questions about drones, sensors, images of real-time collection of data, and data analytics). Example highlights from Year 4 (***RET Program*** *in its own section, above*):



Figure 4E.4 (a) IoT4Ag Partner FLY CITRIS drone flying with Merced Youth Soccer Association. (b) 4-H Academy Cutebot workshop at Purdue (c) Ag Adventures elementary school visit to NFREC Quincy and (d) Food & Ag Festival visitor chats with UF IoT4Ag faculty and students.

FLY CITRIS: IoT4Ag partner, UC Merced's Center for Information Technology Research in the Interest of Society (CITRIS), deployed CoDrone EDU kits to excite students of all ages with activities that program and plan the drone missions. An IoT4Ag faculty added Agricultural content to these events. (**Fig. 4E.4a**).

4-H Academy: Purdue Extension hosts a 2.5-day program for high school students to learn about Ag-related disciplines and careers. IoT4Ag ran a coding workshop using Cutebots for a Smart Farm scenario (**Fig. 4E.4b**).

Ag Adventures: A week-long event is held at the University of Florida's North Florida Research and Education Center (NFREC) in Quincy, FL. Local schools bring their classes to learn about agriculture and science. IoT4Ag students and faculty engaged with approximately 200 third, fourth and fifth graders at stations that featured a robot and thermal camera and an Agribugs (IPAB) drone demo (**Fig. 4E.4c**).

Alachua County Farm Bureau Food and Agriculture Festival at the **Cade Museum for Creativity and Invention**: An IoT4Ag team showed visitors some of the exciting features of drones, sensors, hardware, and real-time data collection from physical devices, and how these technologies are changing how farmers manage their crops (**Fig. 4E.4d**). IoT4Ag has partnered with the Cade Museum, in Gainesville, FL, since 2022.

ACLAMO Camp: ACLAMO summer camp programming ("ACLAMO") is a partnership with Penn's Morris Arboretum (Morris). Morris hosts a 6-week, half-day, free camp for middle school kids from ACLAMO, a non-profit that provides services for Latinos and other community members. In 2023, IoT4Ag provided weekly 1-hour sessions at Morris for the campers (N=48 registered) and hosted the campers at the Penn campus for an all-morning fieldtrip (**Table 4E.1**). Sixth and 7th graders often repeat the camp until they start 9th grade. This is a great opportunity for sharing IoT4Ag-related activities at different stages in the kids' development. It also requires developing content to serve both the kids who are new (and typically younger) and those who were campers in previous summers (IoT4Ag provided programming starting summer 2022; the July 2024 IoT4Ag ACLAMO engagement will be described in the next report).

Table 4E.1 IoT4Ag topics for 2023 ACLAMO middle school students.

2023	IoT4Ag EXCITE lesson plans
July 5	Experiments, Data, Predictions – set up grass growing experiment
July 11	Tech meets Ag – Smart Cutebot coding, controlling robots & moisture sensing applications
July 20	Tech meets Ag – Wind farming, sensors, building an anemometer
July 25	Penn Campus Tours, Demos: Singh Center for Nanotechnology fabrication & characterization facilities, GRASP Lab robotics
July 31	Ag resources – Water, making water filters
August 8	Energy Sustainability & Soil – Making Potato batteries, data analysis of grass in saline & alkali soils

EDUCATE for an Inclusive World: EDUCATE *for an Inclusive World* reinforces that inclusivity is one of IoT4Ag's **core values** and that the Center's programs work to empower those who are already in higher ed environments **to navigate the richness of ideas** and **interactions** that **inclusivity brings** and to continue work towards making **STEM and Ag education** and

career paths visible, **exciting**, and **full of opportunity** for those who might like to pursue them. IoT4Ag EDUCATE provides opportunities for college students through postdoctoral fellows who are considering STEM and agriculture higher education and/or careers requiring research-based training, and for individuals who mentor and support these populations. *The **REU Program** is highlighted in its own section.* Example highlights from Year 4:

Research & Professional Development for **IoT4Ag Trainees** (students and postdoctoral fellows): IoT4Ag trainees are the **critical workforce** that makes the Center's research and many of the EXCITE activities possible. EDUCATE programs supporting our Center trainees are arguably the **most structurally important** for **IoT4Ag's mission** in IoT4Ag E^3.



Figure 4E.5 April 2024 monthly seminar hosted by Purdue with D. Bullock (UIUC) presenting on his Data Intensive Farm Management 9DIFM) research on "bit" agronomic data for fertilizer management.

In addition to conventional departmental and lab-based training received by trainees at their universities, the Center provides **training** in support of its **strong convergent research** and **innovation ecosystem** environments. The Center hosts monthly research seminars, research thrust meetings, testbed office hours, and Center-wide meetings covering topics across all foundational components. Research seminar hosting rotates among the Center sites, which allows the trainees at host sites to **engage** with the **external seminar speakers in-person (Fig. 4E.5**).

IoT4Ag trainees also develop **mentoring skills** by working with summer REU students (see **REU section**) and with undergraduates and master's students on their research projects. **29 undergraduates** (N=7 Purdue, N=8 UC Merced, N=8 UF, N=6 Penn) and **15 master's students** (N=3 Purdue, N=4 UF, N=8 Penn) worked on IoT4Ag projects with IoT4Ag PhD and Postdoctoral Fellows during the 2023-2024 academic year.

IoT4Ag's **Student and Postdoctoral Fellow Leadership Council** (SPLC; N=9 1-yr leadership positions) hosts the **Triannual Check-Ins** to take the pulse of the trainee community, respond to **trainee suggestions,** and provide a forum for formal feedback and **voice** to the **Center's leadership team** and to **NSF**. The SPLC has **liaisons** on **Innovation Ecosystem**, **EWD** and **DCI working groups**; these trainees **contribute** valuable **input** on and **support** the **execution** of the IoT4Ag E^3 Empowering People Portfolio. The SPLC **Professional Development** (PD) Chair works with the Center Leadership team to offer resources to trainees for **building transferable skills**, **practical knowledge** for making transitions into next **academic** or **career stages**, and larger **professional networks**. SPLC leaders, including the students in the two new Campus Liaison roles, organize social, admin-planning, and team-building activities at their local institutions.

Intensives, **Exchanges**, **and Internships**: COVID-19 forced IoT4Ag to start with remote-only activities when the Center launched in 2020; however, ERCs intrinsically have the non-trivial challenge of **building research**, **innovation**, and **educational community** across the **distance** and **time zones** spanned by their partner sites. This is particularly true for trainees, who are still in the process of establishing professional identities and networks. To encourage active Center engagement and a sense of affiliation, while also increasing research and skills competencies, the Center supports meaningful in-person engagement opportunities:

- **Center-wide Boot Camp** led by IoT4Ag's SPLC, is an annual 1.5-day intensive preceding the Center-wide Annual Retreat. The Year 4 Bootcamp (UC Merced, June 2024) agenda included a mixer with the Center's Industry and Agricultural Advisory Board members, a panel focused on research translation and venture capital organized by the executive director of the Valley Institute for Sustainability, Technology and Agriculture (VISTA) at UC Merced, and a tour of California's newest State Park, Dos Rios. A priority of the annual Bootcamps is providing a stimulating, fun forum for students and postdocs from all of our campuses to build connections with each other and a feeling of belonging to the Center (**Fig. 4E.6a**).



Figure 4E.6 (a) Boot Camp 2024 IoT4Ag trainees and REU students at Dos Rios State Park. (b) ITEX: Merced PhD student M. Mortazai visits Purdue's Cappelleri lab to accelerate knowledge transfer in developing a version the autonomously navigating and leaf sampling robot P-AgBot.

- **Intra-ERC Technical Exchange (ITEX)** is a program that fortifies research and professional interactions across the IoT4Ag sites by providing travel and lodging for trainees to visit and collaborate on research with a Center site other than their own. Thus far, 17 trainees (N=8 in Year 4) have engaged with IoT4Ag campus communities beyond their own through ITEX (**Fig 4E.6b**).
- **Industry Internships** are actively encouraged, especially for student placements within IPAB member companies (**Appendix Table 4E.4** lists Year 4 participants).

Formal Education for Broader College and University Audiences: During the 2023-24 academic year, 5 Undergraduate, 30 Master's, and 1 PhD student completed ESE 5150: Internet of Things Sensors and Systems (Penn, C. Kagan). The ME 149: Novel Technologies in Agriculture (R. Ehsani) was not taught in Year 4, as Ehsani's efforts have been devoted to the creation of a new Ag Tech Major at UC Merced. He anticipates teaching ME 149 again in Year 5. These IoT4Ag courses were developed in the first year of the Center driven by the ERC grant.

The development and sponsorship of senior engineering design projects that integrate principles of precision agriculture provided another mechanism for the Center to engage undergraduate students. During the past academic year, 9 IoT4Ag-related senior capstone design projects were completed, involving 30 students; 5 projects involved faculty from multiple partner universities.

STEM Pathway-Building Programs for Broader College and University Audiences: Students who are not matriculated at an IoT4Ag campus are served by our **REU** Program (see **REU section**). Our established partnership with **Santa Fe College** (SF) in Gainesville, FL connects IoT4Ag with SF's **community college (CC)** students. Each Spring, UF-based IoT4Ag graduate students visit SF to increase awareness of Ag-Tech, IoT4Ag research, and related academic and career paths. We have had 4 SF students participate in our REU program and 1 SF undergraduate researcher (2022-2024). 2 **Merced College** (CC) students participated in the 2024 REU and we continue to strengthen this relationship. One of our Advisory Board Members, V. Fuentes, has deep CC expertise and provides valuable guidance for our CC engagement plan.

ENABLE Professional Advancement: ENABLE reaches individual professionals to **empower** them to **incorporate Ag-Tech components** and **systems** into their work and to **advance** their own **career goals**. ENABLE **facilitates translation** and **adoption** of IoT4Ag's **Convergent Research**

and Innovation Ecosystem outcomes toward **systemic change** in agricultural and educational practice.

Specifically, IoT4Ag enables professional advancement of a) professionals/end users-connected directly to agriculture, Ag education, and technology development and b) professionals in education who influence STEM pathways of youth and students in higher ed. We discuss **Ag practitioner** programs in this report section. The Research Experiences for Teacher Program is described in the above **RET** section and categorized in IoT4Ag E^3 under EXCITE given the RET's goal of reaching youth and catalyzing systemic change for EXCITE audiences. Example highlights of professional/end user ENABLE programs and activities from Year 4 include:

Conferences and Expos: The Center organizes and participates in professional conferences and exhibits to share IoT4Ag research, testbed projects, and emerging tech. Conferences and exhibits include the NTCA Fall Conference on Forging the Future of Rural Broadband, the World Ag Expo 2024 (100,000+ attendees representing 49 states, District of Columbia, and 81 countries), SW Florida Precision Agriculture Technology Expo 2024, CITRIS+EDGE in Tech Symposium, San Joaquin Valley Gathering & Small Farm Tech Expo, the Mid-Atlantic Crops Conference, and Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS) National Conference (**Fig. 4E.7**, **Appendix Table 4E.5**; and **Section 4F. Diversity & Culture of Inclusion**).



Figure 4E.7 IoT4Ag Purdue team at the 75th Annual Corn Improvement Conference (organized by IoT4Ag faculty member D. Quinn, Center students presented research at the poster session; February 2024), CITRIS_EDGE in Tech Symposium at UC Merced (IoT4Ag faculty member E. Hestir moderated a panel; March 2024).

Workshops, Presentations, and Demonstrations: IoT4Ag organizes workshops and gives presentations and demonstrations to share advances in IoT4Ag research and farming practices and gain the voice of the stakeholder community in IoT4Ag research and innovation. These engagements include Project 24_BIOPHYSICS which held a workshop with growers to share and get feedback on its real-time decision support tool (see **Section 4C. Convergent Research**). The Center also engages growers and Ag professionals at university agriculture extension research and education centers (e.g., UF's NFREC, Purdue's ACRE, and UC Merced's Smart Farm) and by traveling and presenting virtually to participants nationally and internationally. IoT4Ag activities include research presentations at Field Days, one example (of many) is "Nitrogen Management of Corn using Precision Technologies," at the Davis Purdue Ag Center and others through events with farmers in Mexico and Canada.

Project 34_ENGAGEMENT is a social science project spanning EWD, DCI, and innovation ecosystem led by UF Department of Agricultural Education and Communication that works with our convergent research foundational component. The project aims to ENABLE Professional Advancement through use of evidence-based approaches to engage end-user growers, work with partner institutions to support engagement in our regions and disseminate educational programs. To build trusted relationships, Project 34_ENGAGEMENT has introduced IoT4Ag and spoken with growers and extension agents to get feedback on barriers to precision agriculture adoption (working in partnership with Project 28_TECH ADOPTION). Engagement activities include presentations and listening at research and education center Field Days, engaging rural families

through community events such as Community Day at the Farm, the Merced County Fair, or the Alachua County Farmers Market, and webinars with broad groups of growers participating such as "Community Engagement for Precision Agriculture: Uniting Producers and Researchers for Sustainable Food, Energy, and Water." IoT4Ag also participated in meetings with organizations such as the Florida Peanut Federation Annual Membership Meeting and Banquet, the Florida Stakeholder Engagement Program (STEP), Latino Farmers Alliance, and AgrAbility (**Appendix Table 4E.5**; also see **Section 4F. Diversity & Culture of Inclusion**).

IoT4Ag E^3 Portfolio has organized and participated in activities for: a) **youth and public audiences** with **EXCITE – Tech Meets Ag** hands-on lessons and fun activities, b) **college students and postdocs** with **EDUCATE for an Inclusive World** to prepare them for their next career stages, and c) **professionals** with **ENABLE Professional Advancement**. These different engagement types, number of events in that category, along with number of participants are listed in **ERCWEB Table 6: Quantifiable Outputs.**

INSTITUTIONAL PARTNERSHIPS

IoT4Ag has initiated or retained partnerships with 51 institutions this past year. The types of partnerships range from core partners, collaborating institutions, non-ERC institutions providing REU students, and pre-college educational partners. The list of institutional partners and types of partnership are listed in **ERCWEB Table 4: Partners**.

RECRUITMENT/RETENTION STRATEGIES

All IoT4Ag E^3 activities reach broad, underserved and historically underrepresented populations. For example, EXCITE activities reach Latino youth through the ACLAMO camp and our RET program reaches underserved schools and K-12 populations. Our DCI group leads specific IoT4Ag E^3 recruitment activities, which are described in section **4F. Diversity & Culture of Inclusion**. Note that many EDUCATE activities work to generally (and valuably) build college level (including 2-year college students) to postdoctoral level STEM pathway options while giving them more background in the development of IoT technologies for more productive and planet-friendly agricultural practices and more broadly impactful in other industry sectors.

Below, we focus on EDUCATE-related recruitment/retention for bringing in and retaining students and postdocs working on IoT4Ag research thrusts.

IoT4Ag's compelling mission and collaborative research, innovation, and education environment make it easy to recruit trainees. Our trainee slots have been filled successfully since the Center started in Fall 2020. 24 postdoctoral associates, and 72 Ph.D., 19 Master's, and 73 undergraduate students have been involved in IoT4Ag research, creating the fundamental knowledge, technologies, and systems for the farm of the future while simultaneously developing skills sets that will enable them to become independent researchers and technology leaders. **Appendix Table 4E.6** tracks our alumni placements once they earn their PhD or complete their postdoctoral positions (3 PhDs and 2 Postdocs moved into new positions in Year 4).

EDUCATIONAL DEVELOPMENT AND IMPLEMENTATION

IoT4Ag E^3 Guiding Principles for Educational Development: We decide whether **to add, evolve, or sunset** IoT4Ag E^3 activities using these principles:

- Activities and their anticipated outputs and outcomes are consistent with the IoT4Ag vision, mission, strategic plan, and at least one of the EWD or DCI logic models (serving both model's anticipated outcomes whenever possible).
- Activities can be delivered with coherence and high quality given the Center's capacity (SWOT Analyses from previous Site Visit Teams and by our Advisory Board reiterate the importance of quality over quantity and strategic decision making for our portfolio).
- Activities contribute to the diversity of our IoT4Ag E^3 portfolio on the continuums of uniqueness, readiness, lifespan, and Center role. A diverse portfolio encourages vision, creativity and iterative improvements around EWD-DCI in an analogous way to how Convergence Research and Innovation Ecosystem work to define, design, develop, deploy, evaluate, and select projects and tech for larger adoption. The balance of the portfolio will necessarily evolve as the Center matures.
- Activities with the highest probability for sustainability and impact will be prioritized as the Center moves towards graduation from NSF ERC support (i.e., Years 9-10).

Assessment & Adjustments for Impact: Ongoing assessment and input from our Advisory Board guide our EWD-DCI portfolio. IoT4Ag defines and then assesses yearly joint EWD-DCI IoT4Ag E^3 milestones (see **Tables 4E.2-4E.4**) to support a 10-year EWD-DCI milestone chart (**Fig. 4E.8**) in service of our EWD and DCI logic models (**Fig. 4E.9** at the end of the document). Our external Evaluation Team is based at Arizona State University (ASU; Lead: A. Boyce). Boyce and/or her students participate in our Annual Retreat and NSF Site Visit, sit in on our working group and Advisory Board meetings, solicit feedback from program participants (surveys, interviews), and provide summary reports that help us understand what is working well and what could be improved. The ASU team is available for consulting and solicits our input about appropriate assessment for evolving and new programs.

Table 4E.2 Summary of IoT4Ag E^3 EXCITE integrated EWD-DCI milestones for Year 4. EWD-led (green); DCI-led (orange); Activities, or some set of them function, as broadening participation activities, which reach underserved institutions or groups and/or those underrepresented in Ag sciences or STEM (orange asterisks ***); if programs are named here as examples, they have been expanded upon in **Section 4E. Engineering Workforce Development** and/or **Section 4F. Diversity and Culture of Inclusion**.

IoT4Ag E^3	Activities	Milestones	Assessment (June 2024)
EXCITE	K-12 Engagement Events*** EXCITE students using IoT4Ag exhibits, demos, lessons and robot/sensor kits in formal and informal educational settings	10+ events, 750+ attendees	13 events, 900+ attendees, of which ~580 attendees*** reached at ACLAMO Camp, Junior MANRRS, a STEM middle school camp at Tuskegee University
	Research Experiences for Teachers (RET)***	2+ teachers	2 teachers in 2023; 4 teachers in 2024. Teachers' schools are predominantly minority serving, with

			>87% economically disadvantaged***

Table 4E.3 Summary of IoT4Ag E^3 EDUCATE integrated EWD-DCI milestones for Year 4. EWD-led (green); DCI-led (orange); Center-led (black); Activities, or some set of them function, as broadening participation activities, which reach underserved institutions or groups and/or those underrepresented in Ag sciences or STEM (orange asterisks***) or if activities facilitate inclusion/belonging/Center affiliation (IN); if programs are named here as examples, they have been expanded upon in **Section 4E. Engineering Workforce Development** and/or **Section 4F. Diversity and Culture of Inclusion**.

IoT4Ag E^3	Activities	Milestones	Assessment (June 2024)
EDUCATE	Graduate Student and Postdoctoral Fellow IoT4Ag Research Education	100+ trainees	115 trainees including 24 postdoctoral fellows, 91 graduate students (72 PhD-level), contributing to and learning from IoT4Ag research since the Center launched in 2020
	Professional Development Programming IN	Deliver IoT4Ag programs that unique to the Center deliver valued trainee professional development and that build Center culture	Trainees participate in 10 Center-wide meetings; 2024 Bootcamp & Annual Retreat at UC Merced; 8 ITEX exchanges; 9 SPLC positions (2 new positions created in Year 4 to meet the need for "Campus Liaison")
	Research Experiences for Undergraduates (REU)***	6+ REU students per summer	28 REU researchers with diverse cohorts of 15 in Year 4 and 13 in Year 3 carry out IoT4Ag research, as IoT4Ag uses campus-based support to expand the size of the cohorts. 7 students from home institutions that are MSIs, primarily Associate Degree awarding, and/or not R1 or R2***
	Non-REU Undergraduate Research	60+ undergraduates	62 undergraduate experiences including 32 undergraduate researchers, 30 undergraduate senior design students
	Community College Engagement***	30+ students and faculty	28 community college students including 25 attendees at IoT4Ag graduate student-led

			agronomy info session at Santa Fe College, 3 REU students with 2 from Merced College and 1 from Santa Fa College
	Pathway to PhD Program also serves as professional development programming for trainees	50+ participants	67 participants including 42 mentees (99 mentee sign ups) and 25 mentors
	Minority-Focused Events/Outreach	5+ events/outreach Note: These activities are unique and not included in other activities listed in the table	4 activities for EDUCATE audiences including NSBE, DEEPenn STEM, Digital Ag Fest, expanded REU promotion

Table 4E.4 Summary of IoT4Ag E^3 EXCITE integrated EWD-DCI milestones for Year 4. EWD-led (green); DCI-led (orange); Center-led or various leads/organizational partners (black); Activities, or some set of them function, as broadening participation activities, which reach underserved institutions or groups and/or those underrepresented in ag sciences or STEM (orange asterisks***); if programs are named here as examples, they have been expanded upon in Section 4E. Engineering Workforce Development and/or Section 4F. Diversity and Culture of Inclusion.

IoT4Ag E^3	Activities	Milestones	Assessment (June 2024)
ENABLE	Engagement events to ENABLE stakeholders' careers through talks, workshops, extensions programs, crop advisor certification, tech demos, and field days	40+ events	# 27 from appendix 4E.5 (subtract 15 for inclusive growers)
	Engagement events to tailored to ENABLE inclusive growers/Ag practitioners including focus/listening sessions and information booths	3+ events Note: These activities are unique and not included in other activities listed in the table	15 events led by Project 34_ENGAGEMENT, including a Crops and Colors at Grow Hub (supports adults having disabilities), webinar to unite producers and researchers, and a Community Alliance of Family Farmers incubator event
	MSI-HBCU Partners Network Program	1+ faculty in residency in an IoT4Ag research group	1 faculty and the faculty member's undergraduate student hosted in May 2024; 1 faculty hosted in July 2024



Figure 4E.8 EWD-DCI joint 10-year milestone chart.

Engineering Workforce Development in Yrs 6-10: IoT4Ag E^3 Development and Implementation

In Years 6-10, the Center will follow our guiding principles to create and sustain a diverse and innovative IoT4Ag E^3 Portfolio along the continuums of uniqueness, readiness, and anticipated lifespan, which guide our EWD and DCI components. We will execute upon and pursue funding to support the scaling and sustainability of our signature initiatives.

IoT4Ag EXCITE will disseminate and **build out** unique, **Signature Initiative curricular activities** that have been developed by IoT4Ag Center members and teachers. The Center will continue to deliver our curricula in partnership with schools, camps, museums, and youth organizations. IoT4Ag will build out its activities working with our advisory board members and new and existing regional and campus partners. Highlights include: Our School District of Philadelphia Advisory Board member who is happy to facilitate the development of relationships with organizations that specialize in delivering STEM education (e.g., OpenSciEd, Youth Engineering Solutions) where IoT4Ag could serve as a content expert for Ag-Tech and Ag systems lessons. At the 2024 ERC Biennial meeting, the IoT4Ag Education & Inclusivity Director Field had a promising first conversation about curricular innovation in partnership with the NSF-supported Engineering For US All. We just made an exciting new partnership with the Philadelphia School District and the Fairmount Water Works to join their ongoing work to add weather stations and sensor/data-based lesson plans to schools (will be described in the Year 5 report). These types of **strategic partnerships** reduce reinvention of existing initiatives or products and places IoT4Ag in a position to deliver larger, systemic infrastructure that has **greater impact**, **reach**, and **sustainability**. For general public audiences, UF is engaged in early conversations with Walt Disney World about partnering with IoT4Ag's expertise to develop technology demonstrations for the Living with the Land attraction at EPCOT. In collaboration with Purdue's Thrust 3 Solar-Powered Remote IoT4Ag Network Gateway (SPRING) team, we are testing the readiness of the SPRING device to be adapted for EXCITE audiences at K-14 schools, at informal education

partner locations, and on IoT4Ag campuses for hosting K-14 field trips. This Signature Initiative would share how data from the field can be collected, analyzed, and used to make informed farming decisions. We will continue cross-institutional participation for events, booths, and other forums where EXCITE lessons and activities are delivered; we will also test expansion of programs currently at one institution (e.g., RET at Penn, 4-H at Purdue) to other IoT4Ag sites.

IoT4Ag EDUCATE will sustain and **scale** the Signature Initiative **Pathway to PhD Program** (PPP; detailed in **Section 4F: Diversity & Culture of Inclusion**). IoT4Ag EDUCATE will continue to support the trainee experience by meeting their interests and enabling their growth, uniquely providing multidisciplinary, cross-institutional, and career-building programs and activities, including the Intra-ERC Technical Exchange, other convergent research and innovation ecosystem training opportunities, and community- and network-building programs like the Boot Camp. We will develop model practices for engaging trainees and for building a robust **Culture of Participation** in the Center, especially among the trainees who have not (yet) served on the SPLC. This engagement will continue to strengthen trainees (and faculty) participation in delivering EXCITE activities and connecting them with ENABLE professionals, so that the **IoT4Ag E^3 Portfolio** serves as **integrated scaffolding** for Center-wide community, mentoring, networking and individual development opportunities, as well as for knowledge- and experience-sharing. We will work with **community college** partners to adapt **programming suited for the diversity of their students' career path aspirations**. These efforts will build on our partnerships with Santa Fe College and Merced College, both which have institutionalized pathways to transfer to UF and UC Merced, and our Advisory Board members, one whose expertise includes associate degree awarding institutions. IoT4Ag faculty will also continue to work to create an Ag Tech major at UC Merced.

IoT4Ag ENABLE will expand IoT4Ag "brand" **recognition** as a **trusted source of** and **partner for innovative Ag-Tech** and **knowledge** to better agricultural practices among growers through Project 34_ENGAGEMENT. IoT4Ag ENABLE will continue to **build** and **institutionalize** the **MSI-HBCU Partners Network Program** (see **Section 4F. Diversity & Culture of Inclusion**) across all IoT4Ag campuses and will partner with alumni to **sustain collaborations** with applications for joint funding and continued research and education exchange. Lessons learned and **model practices** of IoT4Ag ENABLE will be **disseminated** in professional conferences, and in web and journal forms.

Together, the **IoT4Ag E^3 Empowering People Portfolio**, in coordination with Convergent Research and Innovation Ecosystem, will prioritize:

- Focused and efficient use of Center capacity to deliver fine-tuned, well executed EXCITE, EDUCATE, and ENABLE activities that balance data-driven, best practice programs (REU, RET) and innovative, earlier-case study Signature Initiative programs.
- Dissemination of IoT4Ag E^3 products and processes (presentations, publications).
- Expanded partnerships for increased impact of IoT4Ag E^3.
- Pursuit of funding and/or partnerships that allow IoT4Ag's products and inclusive education and workforce programs to continue to increase food, energy, and water security with the power of Ag-Tech post ERC-graduation (see Self-Sufficiency Business Plan).

CROSS-INSTITUTIONAL ACTIVITIES

Center Direction, Collaboration, and Seminars: Regularly scheduled working group meetings for administration, research, education, and innovation ecosystem bring together participants who

span IoT4Ag's institutions, including members of the ASU Assessment team (see **Organization Chart** for Center structure). Center-wide Meetings bring invited speakers to IoT4Ag to share their research or innovation-relevant expertise; hosting of these events rotates among the 4 institutions (**Appendix Table 4E.7**). For all-hands-on-deck topics, the Center-wide Meetings provide a forum to share new Center developments and solicit dialogue (2024 topics included: IP and Invention Disclosure; Testbed Leader Panel and Database Protocols, Tech and Adoption Readiness).

IoT4Ag E^3 activities: EXCITE-EDUCATE-ENABLE activities bring IoT4Ag participants together. Year 4 examples include Cutebot programming workshops for the Junior National Society for Minorities in Agriculture, Natural Resources and Related Sciences (JrMANRRS), which brought together Penn and Purdue members for 1 event and UF and Purdue members for another event (see **Section 4F. Diversity & Culture of Inclusion**); the Intra-ERC Technical Exchange program and Center-wide Boot Camp (see EWD ERC Participant Engagement section), and the IoT4Ag exhibit booth at World Ag Expo 2024 (UC Merced and Penn).

Intra-ERC and Inter-ERC events: The most significant IoT4Ag event uniting Center members in time and space is the Annual Retreat. The Retreat comprises talks, panels, posters, tours and opportunity to collaborate with and get to know other Center members. Hosting rotates among the 4 Center institutions with the June 2024 hosted by UC Merced (Boot Camp and Retreat Agenda in **Appendix Fig. 4E.1**). IoT4Ag trainees are also active with other ERCs (the current President of the Inter-ERC Student and Postdoctoral Fellow Leadership Council is an IoT4Ag student). She and her colleagues have organized Tri-Center Gatherings (IoT4Ag, NEWT, and CASFER), including a virtual poster session with awards, and have served in a High School Mentorship Program (NEWT hosted). IoT4Ag staff participate in inter-ERC meetings around EWD, DCI, innovation ecosystem, and Center Admin topics.

RESPONSE TO SWOT

Weaknesses:

- The SVT believes the Center's EWD and DCI efforts look disjointed and appear to be more opportunistic than strategic. This may be in part because of a lack of detailed goals and/or lack of interaction with the EWD and DCI Advisory Boards. It could also be that there are not sufficient funds allocated to these ERC Pillars. Some SVT members suggested reallocation of Center funds to support these activities.

RESPONSE:

Thank you for the comment. IoT4Ag took the SVT feedback seriously! In Year 4, IoT4Ag established a new Director of Education and Inclusivity position and hired Dr. Kristin Field, who has 11 years of experience leading education and inclusion programs for multi-PI NSF grants. In partnership with our advisory boards and in response to feedback from last year's NSF Site Visit, we undertook an evaluation of the structure, function, and integration of our EWD and DCI programs and activities to ensure intentionality and to deliver on our goals. Field led the Center to execute the strategic integration and implementation of IoT4Ag's Action Plan for EWD and DCI programs. We introduced the IoT4Ag Empowering People Portfolio, we call for short, **IoT4Ag E^3** for EXCITE - Tech

Meets Ag, EDUCATE for an Inclusive World, and ENABLE Professional Advancement (**Fig. 4A.3, bottom**), and we established a set of guiding principles to ensure the selection, creation, execution, and sustainability of our portfolio of programs and activities, as described above and in **Section 4F. Diversity & Culture of Inclusion**. We also formed a singular EWD-DCI advisory board that operates as one in meeting and providing IoT4Ag guidance.

Threats:

- The 2022 SVT suggested "[there was very limited interaction (almost null) with EWD Advisory Board and DCI Advisory Board. There appeared to be no coherent interactions across advisory boards.]" In response to this, the SVT recognizes the Center attempted to develop strategies, for this reporting year, to effectively engage these Boards. Having said this, the SVT believes the Center needs to re-think its approach. The highly qualified members of both Boards are eager to be active participants and help the Center achieve its EWD and DCI goals. The SVT would like to see a more detailed Board engagement plan.

RESPONSE:

Thank you for the comment. In response to the 2023 SVT report, we worked with our EWD and DCI boards to join these bodies, forming a single EWD-DCI Advisory Board. The Board met jointly in January, April, and July 2024. We have worked with the Board in establishing the IoT4Ag E^3 Portfolio along the continuums of uniqueness, readiness, and anticipated lifespan, and about the strategic collection of best-practice and case-study Signature Initiative programs for IoT4Ag EXCITE, EDUCATE and ENGAGE. We have responded to the Board's annual SWOT (July 2024) that will inform our Year 5 activities and contribute to our success in implementing IoT4Ag E^3. We continue to build on our engagement with the Board, having invited members to receive our weekly Center updates, and we will roll out a Dashboard in Year 5 to quickly see IoT4Ag E^3 progress and to be able to initiate engagement beyond the Board meetings. Within the IoT4Ag E^3 framework, we are tapping into the expertise and networks of individual Board members for EXCITE (Philadelphia School District-Fairmount Water Works Partnership and Year 6-10 plans) and for recruitment for EDUCATE programs, like the Pathway to PhD Program (PPP, **Section 4F. Diversity & Culture of Inclusion**). Year 5 will deepen our participation with Board members around EDUCATE and ENABLE (e.g., community college and DCI-led programs, including the PPP and MSI-HBCU Partners Network Program).

Middle-Band Requirements:

- There is a missed opportunity on targeted recruitment from underrepresented groups into the REU programs as it seems that recruitment is only done at the NSF site and word of mouth.

RESPONSE:

We agree. 2024 REU Program promotion, in addition to being listed on the NSF site, was sent out to contacts at: Pathways to Science (a national clearing house for opportunities that increase STEM diversity), 12 HBCU or MSI institutions, and 3 societies or targeted recruitment programs (MANRRS, SACNAS, DEEPenn STEM (at Penn)). For the 2024 REU, we received 206 applications compared to 143 in 2023. Of the 15 students in the 2024 cohort that responded to demographic questions, 6 students (40%) identified as women, 9 students (60%) reported being non-white or multi-racial, 4 (27%) identified as

Hispanic or Latino. We continue to add onto our broadening participation list for promoting the REU and other IoT4Ag E^3 programs.

- Staff and students are engaged in the EWD program, but it appears that not enough faculty are engaged. They should be more involved in the EWD efforts.

RESPONSE:

Faculty were/continue to be engaged in outreach and education events. For example, these include Bill Eisenstadt at the Food and Agriculture festival at the Cade Museum; Dave Cappelleri, Dennis Buckmaster, Jim Krogmeier, David Love, Dan Quinn, and Melba Crawford at the Digital Agriculture Festival at Purdue University; Ian Small at farmer engagement events such as a conservation and integrated livestock meeting, an integrating digital Ag technology into sustainable cropping systems meeting, and Smart Ag; Cherie Kagan and Troy Olsson at a Program.IT at FluxSpace in Norristown PA and Computer Science OneDay at Lower Merion High School; Katie Stofer at community / stakeholder engagement workshops; David Arnold at the Sante Fe College and Ag Adventures with Charlie Messina at University of Florida; Sue Ann Bidstrup-Allen at ACLAMO summer camp; Erin Hester at the Bobcat Summer STEM Academy at University of California Merced; Dennis Buckmaster at an Agriculture workshop at Purdue University; and Jim Krogmeier at an Ag Gateway Annual Conference. Faculty are excited to participate in these events and we will more clearly state faculty involvement in the upcoming annual reports See Appendix Table 4E. 8 for a full list of faculty engagement in outreach and education events during Year 4.

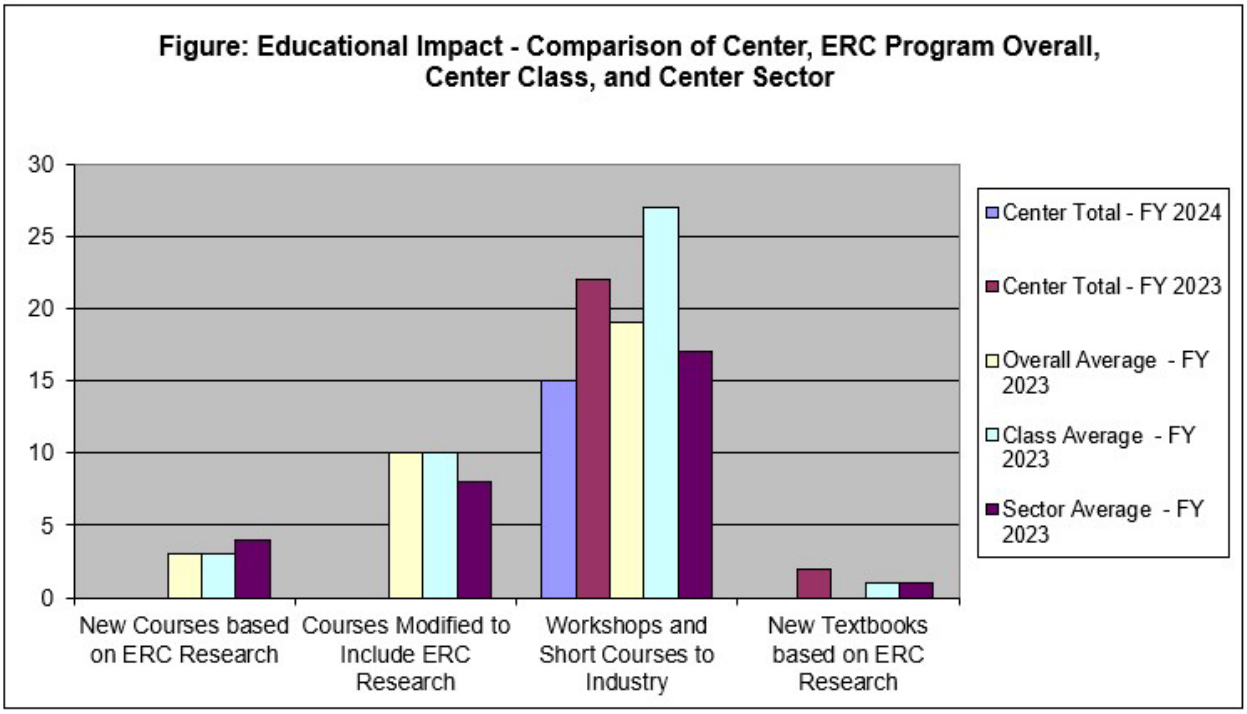
INPUTS & RESOURCES	ACTIVITIES	OUTPUTS	OUTCOMES		
			KNOWLEDGE SHORT-TERM	ACTION MEDIUM-TERM	IMPACTS LONG-TERM
•NSF funding and ERC program resources •Talented and dedicated university faculty and staff •Excellent research and teaching facilities •K-12 teachers and museum coordinators committed to STEM education •Existing relationships with under-represented K-12 and university organizations •Partnerships with Ag-focused community college programs •High quality undergraduate and graduate programs •Agricultural extension agents focused on bringing new technologies to growers •Growers, Ag professionals, and grower organizations seeking to improve crop production •Existing international exchanges and training programs focused on agriculture •EWD-DCI advisory board members	EXCITE •Create IoT4Ag mission-driven, research-relevant lessons, hands-on activities, demonstrations for K-12 and general public audiences •Build relationships with K-12 teachers with RET program, IoT4Ag visits to schools, class visits to IoT4Ag •Learn about and develop partnerships with schools, school systems, formal and informal educational organizations and dissemination platforms EDUCATE •Engage Community College (CC) faculty and students •Provide undergraduate academic and research opportunities •Train graduate students and postdocs (trainees) for deep convergent research competency and broad transferable professional skills ENABLE •Provide growers, Ag professionals, practitioners, organizations resources related to IoT4Ag research and products •Understand and build Ag stakeholder-university engagement, and translation-adoption pathways for Ag-Tech products	EXCITE •Lesson plans and activities for formal and informal education that are easily teachable, flexible, engaging for audiences •RET program (hosted teachers, new IoT4Ag-based lesson plans); Students engaged by IoT4Ag teams in their classrooms or at IoT4Ag universities •Partnered activities, events, projects, dissemination EDUCATE •Information sessions at CCs, IoT4Ag materials for CC students about Center; Discussions with CC faculty about student and institutional needs related to IoT4Ag •New courses, senior design project supervision, REU and academic year research opportunities •Convergent research projects, Translation-Innovation training, Center-wide seminars, Intra-ERC Technical Exchange, Boot Camps, Annual Retreats, Professional Development workshops, Leadership Opportunities ENABLE •Talks, workshops, extension programs, crop advisor certification, tech demos, field days, exhibit booths •Research projects that also train student researchers	EXCITE •Understanding of best practices – What lessons/activities work in different settings, Who to train and How to deploy •RET Program: develops IoT4Ag lesson plans, enables teachers to develop, pilot, teach materials to meet their students' needs and curricular standards •Understanding between IoT4Ag and partners of what to collaborate on and how to work together EDUCATE •IoT4Ag understanding of CC student academic and career paths and CC institutional structures; CC students/faculty more aware of precision Ag pathways; CC student participation in REU •Students at IoT4Ag institutions and externally know about Center-related opportunities •Trainees are engaged in, contributing to, and learning from research, academic, professional development activities of the Center ENABLE •Growers, Ag practitioners and professionals know about IoT4Ag's mission, research, opportunities for participation •Data collection: learning from stakeholders and from tech researchers and developers	EXCITE •IoT4Ag teams and partners lead lesson plans/activities; Lessons/activities made web-accessible to all educators and learners •Educators continue to use and build upon IoT4Ag lessons; IoT4Ag supports their efforts (materials, expertise) •Development of strategic evolving portfolio of activities, events, projects, partners aligned with IoT4Ag EDUCATE •CC students join IoT4Ag research projects; collaborations developed between IoT4Ag and CC faculty/administrators to identify and act on activities/materials effective for CC student/institutional needs •Students take IoT4Ag-related courses, participate in mentored research and design projects •IoT4Ag supports trainees with infrastructure, mentorship; trainees contribute to the Center; Trainees advance their academic paths, graduate, secure designed positions ENABLE •Enable individual practitioners to learn about and use new research and products/systems for farming; Foster and strengthen participation and early partnerships •Disseminating results and implications for stakeholder engagement and adoption of emerging Ag-Tech	EXCITE •Diverse K-12 and general public audiences learn about how tech can meet the needs of Ag and connects to food, energy, and water security; IoT4Ag trainees build science communication skills •The number of classrooms and students exposed to and excited by precision Ag and food-energy-water sustainability increases •Pedagogical tools used and disseminated by external organizations; IoT4Ag is seen as a resource for Ag-Tech education and outreach EDUCATE •Built capacity for 2 and 4 year institutional collaboration to prepare CC students for careers in and related to Ag-Tech •More undergraduates exposed to precision Ag, pursue Ag-Tech paths, translate knowledge from Center activities to build desired career paths •Trainees prepared and excited to translate their expertise for impact on societal grand challenges in a variety of Ag, STEM, and adjacent disciplines ENABLE •Industry-Academic-Government-NGO Partnerships for advancing Ag-Tech, including workforce training •Growers, practitioners, and related industries feel IoT4Ag technologies are relevant to their businesses and prepared to use them

Figure 4E.9 Engineering Workforce Development Logic Model

ERCWEB TABLE 10: EDUCATIONAL IMPACT

Table: Educational Impact														
	Total from Quantifiable Outputs Table	With Engineered Systems Focus		With Multidisciplinary Content		Team Taught by Faculty From More Than 1 Department		Undergraduate Level		Graduate Level		Used at More Than 1 ERC Institution		Cumulative Total for All Years
		Jul 01, 2023-Jun 30, 2024	Percent	Jul 01, 2023-Jun 30, 2024	Percent	Jul 01, 2023-Jun 30, 2024	Percent	Jul 01, 2023-Jun 30, 2024	Percent	Jul 01, 2023-Jun 30, 2024	Percent	Jul 01, 2023-Jun 30, 2024	Percent	
New Courses Currently Offered [1]	0	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2
Currently Offered Ongoing Courses With ERC Content [2]	0	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	2
Workshops, Short Courses, and Webinars	15	2	13%	3	20%	3	20%	2	13%	3	20%	1	7%	73
New textbooks based on ERC research	0	0	0%	0	0%	N/A	N/A	0	0%	0	0%	0	0%	2

ERCWEB FIGURE 5: EDUCATIONAL IMPACT



[1] New courses currently offered and approved by the curriculum committee are only counted in the first year that they are offered so there is no multiple counting of these courses.

[2] The cumulative totals for "Currently offered, ongoing courses with ERC content" may count the same course more than once.

This is due to the fact that a single course can be modified in multiple years and therefore will be included in the cumulative total multiple times.

[3] Educational impacts/outreach activities may result from activities initiated as part of the ERC Engineering Workforce Development, Diversity and Culture of Inclusion, and Innovation Ecosystem.

ERCWEB TABLE 11: RATIO OF GRADUATES TO UNDERGRADUATES

Table: Ratio of Graduates to Undergraduates							
Center Grouping	**Undergraduates**	**Graduate Students**	**Ratio Grad/UG**	**REU Students**	**Total College Students**	**Young Scholars**	**Total Students (Graduate, Undergraduate, Young Scholar, and REU Students)**
Average All Active ERCs FY 2023	34	68	2.0	13	116	9	125
Average Micro/Optoelectronics, Sensing, and Information Technology Sector FY 2023	22	69	3.1	12	103	4	107
Average for Class of 2020 FY 2023	54	83	1.5	15	153	7	160
IoT4Ag FY 2023	39	73	1.9	23	135	0	135
IoT4Ag FY 2024	**32**	**80**	**2.5**	**28**	**140**	**0**	**140**

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4F. DIVERSITY AND CULTURE OF INCLUSION

SUMMARY OF GOALS & ACCOMPLISHMENTS

Goals: For *all* foundational components, IoT4Ag puts into practice the vision that **agriculture** and **STEM academic**, **research**, and **career paths** are **exciting**, **welcoming**, and **full of opportunity**. The Center strives to foster a culture of inclusion and belonging that a) includes, and transcends, courtesy, collegiality, and respect within its own Center-wide community and b) radiates out to everyone who interacts with our community.

A key framework for implementing these goals is the **IoT4Ag Empowering People Portfolio: Excite-Educate-Enable (IoT4Ag E^3)**, which is described in detail in **Section 4E. Engineering Workforce Development (EWD)**. IoT4Ag E^3 is one of the key interfaces for interactions between our internal and external Center communities; the other key internal-external community interfaces occur through the Convergent Research and Innovation Ecosystem. With the guiding principle that **Diversity and Culture of Inclusion (DCI)** truly **underpins all foundational components**, here we elaborate on the DCI-led programs and activities for IoT4Ag E^3.

Key Accomplishments:

- Launch of **IoT4Ag E^3**
  - Accomplishment: With Year 4, IoT4Ag created the Director of Education and Inclusivity position and hired Dr. Kristin Field. IoT4Ag E^3 was rolled out to strategically integrate and implement IoT4Ag's EWD and DCI programs.
  - Impact: IoT4Ag DCI goals are integrated with engineering workforce development activities and articulated to underpin the Center holistically.
- **EXCITE** – Tech Meets Ag
  - Accomplishments:
    - Lesson plans and curricular activities delivered at sites and events that reach underserved and/or historically underrepresented audiences in agricultural, Ag-Tech, and STEM disciplines (e.g., ~580 6th-12th graders reached in programming delivered to a) middle school campers from ACLAMO, a Latino-focused Community-Based Organization, b) Junior MANRRS, the youth component of the National Society for Minorities in Agriculture, Natural Resources and Related Sciences, and c) a STEM middle school camp at Tuskegee University).
    - IoT4Ag- and Ag-Tech-related content in RET program teachers' schools, which have student populations underrepresented in Ag-Tech and STEM (see **Section 4E. Engineering Workforce Development** and **Appendix Table 4E.3**).
    - Lesson plans on our webpage accessible for educators and learners *anywhere*.
  - Impact: IoT4Ag EXCITE engages broad, diverse youth audiences and the public in formal and informal learning environments about cutting edge technology creating "farms of the future" and about the opportunities that STEM and agriculture career paths allow for securing food, energy, and water security.
- **EDUCATE** for an Inclusive World
  - Accomplishment:

- The **Pathway to PhD Program (PPP),** an IoT4Ag **Signature Initiative**, continues to grow, matching in Year 4 42 mentees interested in learning about graduate admissions and funding with 25 PhD students and postdocs mentors from IoT4Ag institutions. Mentors provided general mentoring and specific feedback on their mentees' personal and research statement drafts; Year 5 matched 104 mentees with 30 mentors.

  - Impact: IoT4Ag EDUCATE DCI-led PPP is increasing accessibility of knowledge about and skills for pursuing advanced degrees in STEM and Ag-Tech, as well as providing mentorship training and opportunity to graduate students and postdocs; after 4 years of piloting this program is now developing its plan for scaling. In the context of IoT4Ag's overall Broadening Participation work, and for the benefit of the IoT4Ag E^3 audiences, the Center and, society at large, IoT4Ag's DCI foundational component is committed to developing an expert-informed, evidence-based action plan to kick off Year 6.

- **ENABLE** Professional Advancement
  - Accomplishments:
    - Building and strengthening partnerships that support inclusive end-user and Ag practitioner participation in IoT4Ag's programs and products and that more generally support inclusivity in Ag-Tech.
    - Year 4 launch of the MSI-HBCU Partners Network, with the first faculty member in residency at an IoT4Ag institution; L. Mei from University of Maryland Eastern Shore (UMES), along with her UMES undergraduate researcher, were hosted by Penn in the Arratia Lab; the start of Year 5 (July 2024) brought a second faculty member from Hampton University to Penn, also hosted by the Arratia lab.
  - Impact: IoT4Ag's DCI-led ENABLE work is slow but deep work. These relationships require investment on all sides, but are multifaceted and have potential to create transformative change for individuals and advance systemic change institutionally.

IoT4Ag E^3 Overview and Structure related to DCI: As stated in **Section 4E. Engineering Workforce Development** (EWD), IoT4Ag aims to a) **Excite** youth and public audiences about STEM and agriculture through fun and engaging activities and by connecting agricultural and physical science and engineering to solutions that benefit society and to the IoT4Ag vision; b) **Educate** college/university students and postdocs and prepare them for rewarding and impactful agriculture and STEM careers in an inclusive world; and c) **Enable** early to established growers and engineering and agriculture professionals to advance their careers and to accelerate their practice, and/or pedagogy, of Ag-Tech systems.

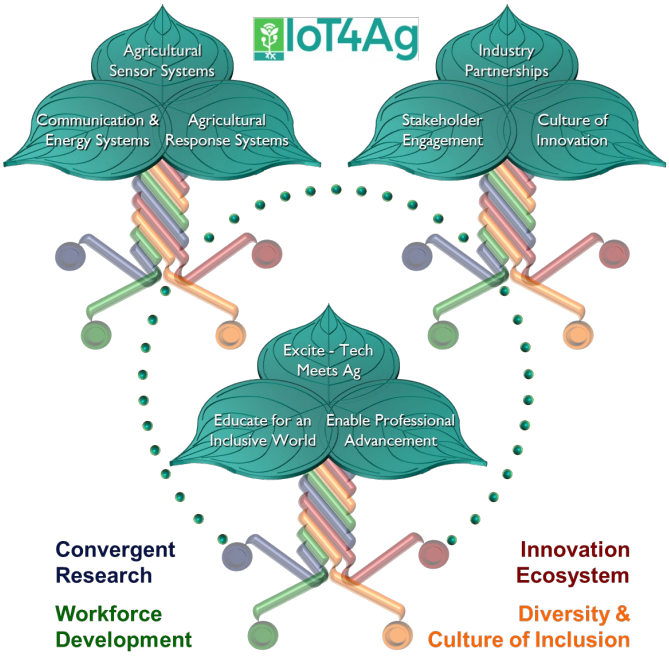


Figure 4F.1 Summary of integrated IoT4Ag thrusts and programmatic axes and their relationship to the four NSF Gen-4 ERC Foundational Components.

The **IoT4Ag Empowering People Portfolio: Excite-Educate-Enable**

(IoT4Ag E^3) is designed to "**grow people**" and **catalyze systemic change** in agricultural and educational practice (**Fig. 4F.1, bottom**). **Section 4E** gives an Overview for and describes the Structure of the **IoT4Ag E^3 Portfolio**. We reinforce here that **EWD** and **DCI** are **inseparable**. Below, we describe the **IoT4Ag E^3** portfolio through the lens of DCI, including but not limited to the DCI-led activities.

EXCITE - Tech Meets Ag: As a practice, the IoT4Ag community prepares and delivers EXCITE demos and activities to be **appropriate** for **specific audiences** and **forums**. The IoT4Ag faculty, postdoc, graduate students and staff who organize, design, and deliver activities are key for EXCITE implementation. For EXCITE audiences who have few models of parents, neighbors and community members in Ag-Tech or STEM careers, the IoT4Ag teams make "engineer," "scientist," "researcher" and "student" labels real and accessible. Center members, in turn, gain more experience with teaching, with communicating the excitement and relevance of their research, and with discussing their career goals with people at different life stages who have a diversity of backgrounds and experiences.

As highlighted in **Section 4E**, one of IoT4Ag's **Signature Initiatives** is the creation of adaptable lesson plans, activities, and curriculum around coding, sensing, robotics, data, computer systems and technology for farming and food, water, and energy security in a changing world. **Smart Cutebot Kits** are a **powerful hands-on** component of many of these EXCITE **lesson plans** and **curricula**, which can be used in formal and informal settings and adapted for the learners' backgrounds, interests, and educational levels.

Inclusive EXCITE Delivery: Here, we highlight bringing the **Smart Cutebot micro:bit coding lessons** to **events** and environments where **youth** from **underserved communities** or **underrepresented populations in STEM and Ag-Tech** are. IoT4Ag gave 4 one-hour workshops at a 2-day Verizon STEM Camp for middle school students, which was held at Tuskegee University (124 students engaged; **Fig. 4F.2a**). In Year 4, there were also two Junior MANRRS, the youth component of the National Society for Minorities in Agriculture, Natural Resources and Related Sciences, events in which IoT4Ag shared the Cutebot coding lessons: 1) an IoT4Ag team visited 2 Indianapolis middle schools that serve primarily students of color to deliver 5 Cutebot workshops (~140 students engaged), 2) at the MANRRS 38th Annual Training Conference and Career Expo in Chicago, an IoT4Ag team excited ~267 students with the hands-on Cutebot coding lessons (**Fig. 4F.2b**); one member of this team also participated on a panel that covered topics including: higher education, STEM fields, agricultural engineering, and staying motivated academically. These EXCITE events also are examples of **cross-institutional activities**; they brought together teams from two of the Center's sites (Tuskegee: UF, Penn; Indianapolis: Purdue, Penn; Chicago: UF, Purdue). **Section 4E.**



Figure 4F.2 IoT4Ag delivered Smart Cutebot lessons at (a) Verizon STEM Camp at Tuskegee University, at b) MANRRS38 in Chicago and, at c) Decatur Stephen School. (d) IoT4Ag exhibit table at Grow Hub.

Engineering Workforce Development describes the ACLAMO camp that serves primarily Latino students.

In addition to these informal education settings, IoT4Ag EXCITE teams visit **schools** with Cutebot coding lessons (e.g. Lower Merion HS's Program.it for increasing diversity in computing; Decatur Stephen School, where 95% of students are economically disadvantaged, **Fig. 4F.2c**). The IoT4Ag RET program accelerates the reach of IoT4Ag curricular materials through partnering with RET teachers, who bring IoT4Ag-motivated lessons to their schools, most of which are in underserved neighborhoods and/or serve diverse populations of learners (**Section 4E. Engineering Workforce Development** and **Appendix Table 4E.3**).

IoT4Ag EXCITE teams share IoT4Ag's mission and work with the **general public** by hosting **tables at festivals** and events, some of which increase **Ag-Tech awareness among minority groups** and their allies (e.g., IoT4Ag's table at the Crops and Colors Festival, at Grow Hub (**Fig. 4F.2d**), a non-profit plant nursery supporting the lives of adults living with disabilities).

EDUCATE for an Inclusive World: EDUCATE *for an Inclusive World* reinforces that inclusivity is one of IoT4Ag's **core values** and that the Center's programs work to empower those who are already in higher ed environments **to navigate the richness of ideas** and **interactions** that **inclusivity brings** and to continue work towards making **STEM and Ag education** and **career paths visible**, **exciting**, and **full of opportunity** for those who might like to pursue them. IoT4Ag EDUCATE provides opportunities for college students through postdoctoral fellows who are considering STEM and agriculture higher education and/or careers requiring research-based training, and for individuals who mentor and support these populations.

Signature Initiative - IoT4Ag's Pathway to PhD Program (PPP): This program makes PhD programs and funding more accessible with an online, intensive workshop and a national network of mentors from IoT4Ag institutions, who represent different regions, disciplines, and experiences, to demystify, guide, and **prepare** mentees for **U.S. graduate STEM** and **Ag education** and **fellowship application processes**. PPP is **open to anyone, anywhere**; it uniquely pairs mentors and mentees and provides **hands-on writing** and **individual feedback** on research and personal statements. Students from under-represented minority (URM) and first-generation low-income (FGLI) backgrounds are often not familiar with the graduate school application process nor how advanced degrees are financed. PPP provides an accessible structure for bringing together undergraduate, master's, and postbac learners with near-peer mentors, who are currently PhD students, postdocs, or early career faculty. Importantly, PPP includes training and mentorship opportunities to doctoral students and postdocs as part of career development.

PPP starts with a mentorship workshop for all mentors followed by an **all-day workshop** on a Saturday in September, which is timed in advance of deadlines for applications to matriculate into PhD programs for the following Fall. The 3rd PPP workshop was held on Sept. 9, 2023, which is described here. The 4th PPP ran on Sept. 14, 2024, and will be described in the Year 5 report. The Saturday session is structured with presentations about the graduate school application and funding process in the morning led by IoT4Ag faculty member P. Arratia (Penn), with contributions from L. Yeo (UC Merced) and a team of PhD and postdoctoral mentors recruited from the 4 IoT4Ag institutions (Penn, Purdue, UC Merced, UF). After the lunch break, the participants ("mentees") join their **assigned mentors** in **small breakout groups** where they work on drafts of personal and research statements. The NSF Graduate Research Fellowship Program (**GRFP**) is used as a **model funding opportunity** to illustrate fellowship application tips and as the case study for

understanding the structure of personal and research statements. The expectation is that mentees, some of whom are not eligible for the GRFP, can take this experience and apply it to the specific applications to which they apply. After the Saturday workshop, **mentors continue to work with mentees** on their written statements and are available to respond to general graduate school questions for **approximately 6-weeks** as part of the formal PPP program. Beyond the program, mentors and mentees are welcome and encouraged to keep in contact should they choose.

PPP participation has grown each year (**Table 4F.1**). For the Year 4 2023 mentee participants (N=42; several of whom chose not to respond to demographic questions): 24 (57%) identified as female (12 or 29% male, 3 or 7% as non-binary); 1 identified as Middle Eastern, 6 (14%) as White, 8 (19%) as Black, 13 (31%) as Asian; 9 (21%) as ethnically Latino. Of the 2023 mentors (N=25) who responded to demographic questions, 10 (40%) identified as female, 6 (24%) as male, 2 non-binary; 3 (12%) identified as Black, 4 (16%) as White, 10 (40%) as Asian; 1 as Latino. For the 2024 mentees, our Assessment team received pre-survey responses from 77 of the mentees (multiple race and ethnicity were chosen in some cases); mentees identified as: woman (65%), Asian (44%), Middle Eastern (19%), White (18%), Black (14%) and Latino (8%). 2024 mentors identified as female (29%), Asian (45%), White (32%), Black (6%), Latino (13%).

Table 4F.1 Pathway to PhD Program Interest and Participation (numbers of individuals)

PPP Year (Report Year)	Mentees Signed Up	Mentees Participated	Mentors
2021 (Y2)	15	15	10
2022 (Y3)	74	38	15
2023 (Y4)	99	42	25
2024 (Y5)	281	104	31

Based on the post-program survey for 2023, our ASU Assessment team concluded, "All respondents unanimously agreed or strongly agreed they had a positive experience after they participated in the PPP program, with only one participant having a neutral view regarding the program organization. This indicates that the program was highly successful and met the participants' expectations." The mentee response rate was 38% (N=16), which we are working with our ASU colleagues to improve for 2024. Mentors who responded to their post-program survey (N=21) were neutral or agreed that "they were satisfied with their experience as a mentor" in 16 (76%) cases (5 disagreed). For 2024, based on our Assessment team's feedback, we increased communications with the mentors (and mentees) to try to level set expectations. The 2024 program is currently ongoing through Oct. 11.

This **Signature Initiative is now** in the **scaling phase**. During the summer of 2024, we had several consulting meetings with Penn Engineering's Office of Instructional Design. These discussions made clear that one option we were considering for scaling (developing PPP into a Coursera-Platform course) would not be the best fit for maintaining the uniqueness of PPP. In Year 5, we will create professional videos, with the support of Penn Engineering Instructional Design, for our IoT4Ag YouTube Channel to provide asynchronous accessibility of PPP content. It is important to continue offering the synchronous, hands-on writing, and mentor-mentee relationship components of the program. We will continue to test ideas that allow for higher throughput delivery *without* losing the unique group-based dynamism that synchronous participation fosters or the personalized mentoring aspects of PPP.

Increasing Visibility of IoT4Ag and Ag-Tech Academic and Career Pathways: IoT4Ag EDUCATE increased targeted promotions of its summer **Research Experience for Undergraduates** (REU Program, described in **Section 4E. Engineering Workforce Development**), which had been suggested by the Year 3 Site Visit Team. Year 4 REU promotion

included these outlets: Pathways to Science (a national clearing house for opportunities that increase STEM diversity), 12 HBCU or MSI institutions, and 3 societies or targeted minority recruitment events (MANRRS, SACNAS, DEEPenn STEM (described below)). For the 2024 REU, we received 206 applications compared to 143 in 2023. Of the 15 students in the 2024 cohort who responded to demographic questions, 6 students (40%) identified as women, 9 students (60%) reported being non-white or multi-racial, 4 (27%) identified as Hispanic or Latino.

An IoT4Ag UF graduate student team visited Santa Fe College, a primarily associate's degree awarding institution, in Year 4, in what has become a yearly tradition to share highlights about IoT4Ag research and their own academic and research trajectories. Over the course of the Center, we have had 3 Santa Fe REU students and 1 dual-enrolled Santa Fe-UF undergrad researcher. Year 4 was the first time community college students from Merced College participated in the IoT4Ag REU. Understanding how IoT4Ag can increase the Center's visibility with and provide appropriate **programming for Associate-degree institutions and their students** is a workforce- and inclusion- goal for the Center in the upcoming year.

Information tables and **exhibit booths** are part of IoT4Ag's DCI-led EXCITE portfolio. Examples include: a) IoT4Ag hosted a table at 2023 **DEEPenn STEM**, a collaboration across 5 schools at Penn, that hosted 69 2nd-4th year college students from across the U.S. on the Penn campus over the October 6 weekend. This event comprised talks, workshops, tours, mentoring, networking and a resource fair for undergraduates who have limited access to information, research, and opportunities in STEM. Nearly 60% identified as female, ~30% LGBTQ+, 40% first-generation, with the most common racial identification being black (~40%) and ~36% identifying as being Hispanic. IoT4Ag will staff a table at the 2024 DEEPenn STEM event this October. b) At Purdue, the Digital Ag Fest, a collaboration of 30 departments in the College of Ag and College of Engineering, increased undergraduate awareness of digital ag. IoT4Ag gave demonstrations of Center research, including those featuring drones and robots, and trainees presented posters on their IoT4Ag research. The event had over 300 sign ups at the stadium (74 undergrads, 85 master's and 163 PhD students registered). c) IoT4Ag sponsored a booth at the National Society of Black Engineers in March 2024 in Atlanta (**Fig. 4F.3**) and, in addition to the MANRRS CuteBot workshops described above in EXCITE, IoT4Ag hosted a career booth at MANRRS38. Towards increasing effectiveness of these types of activities, IoT4Ag UF faculty member leading Project 34_ENGAGEMENT has written, with UF and Purdue trainees, and a Purdue faculty member as co-authors, 3 articles for publication to the Electronic Data Information Source of UF/IFAS Extension. These articles share best practices for delivery of effective outreach motivated by these IoT4Ag members' experience at MANRRS38.



Figure 4F.3 IoT4Ag exhibits at NSBE, March 2024, Atlanta.

We continue to enhance our broadening participation strategies for sharing IoT4Ag's mission, Ag-Tech's potential for transforming farming, and promoting the REU and other IoT4Ag E^3 programs.

EDUCATE Across IoT4Ag's Foundational Components for IoT4Ag Trainees: Section 4E. Engineering Workforce Development shares our convergent research and professional development training across the Center's foundational components for our graduate students and

postdocs ("trainees"). We reinforce here in this DCI-section of the report that the Center-wide Annual Retreat and Cross-Institutional Activities are ways in which the Center facilitates well-being, affiliation to the Center, and a sense of community and belonging. The SPLC, Triannual Check-Ins, the student-led Boot Camp, and the PPP provide important mechanisms for trainees to build community and have agency in shaping the Center.

ENABLE Professional Advancement: ENABLE reaches individual professionals to **empower** them to **incorporate Ag-Tech components** and **systems** into their work and to **advance** their own **career goals**. ENABLE **facilitates translation** and **adoption** of IoT4Ag's **Convergent Research and Innovation Ecosystem outcomes** toward **systemic change** in agricultural and educational practice. Specifically, IoT4Ag enables professional advancement of a) professionals/end users-connected directly to agricultural, Ag education, and technology development and b) professionals in education who influence STEM pathways of youth and students in higher ed. We discussed the RET under EWD-led EXCITE and the **Ag practitioner** programs in detail in the EWD-led ENABLE (**Section 4E. Engineering Workforce Development**). Here, we briefly reinforce aspects of the practitioner programs aimed at inclusive participation and partnering. We then detail one of our Signature Initiatives.

Ag Practitioner/End-User Inclusivity: Project 34_ENGAGEMENT has introduced IoT4Ag and spoken with growers and extension agents to get feedback on barriers to precision agriculture adoption (working in partnership with Project 28_TECH ADOPTION). This work has prioritized diverse participation with its outreach to and partnering with organizations including, Community Alliance of Family Farmers (CAFF), Latino Farmers Alliance, and AgrAbility (ENABLE activities listed **Appendix Table 4E.5**). Both UF- and UC Merced- Center teams have engaged with CAFF (**Fig. 4F.4a**). At the Center-wide Annual Retreat at UC Merced, the Stakeholder Engagement panel included spokespeople from CAFF, Latino Farmers Alliance, and Penn State Extension (who also serve on the Center's Ag-Systems Advisory Board) and was organized and moderated by UF IoT4Ag faculty member K. Stofer (**Fig. 4F.4b**).

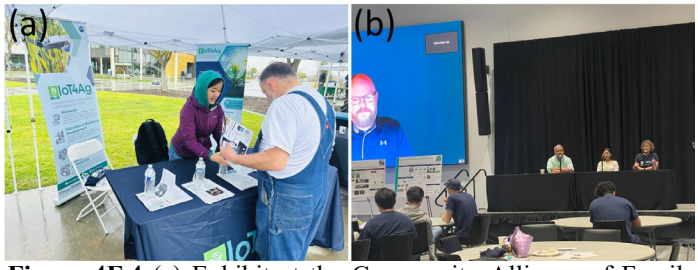


Figure 4F.4 (a) Exhibit at the Community Alliance of Family Farmers San Joaquin Valley Gathering & Small Farm Tech Expo – 2024, b) Stakeholder Panel at Annual Retreat.

Signature Initiative - MSI-HBCU Partners Network Program: This Minority Serving Institution - Historically Black Colleges and Universities (MSI-HBCU) Partners Network Program hosts faculty at IoT4Ag research laboratories. The long-term goal is to establish strong and sustainable partnership with MSI-HBCU institutions through collaborative research and education. MSI-HBCU faculty are invited to bring a student from their institution, if a student would benefit from and amplify the outcomes of the residency. The Program expands the research, education, and resource base for participating faculty and their students to share with their peers and home institutions. In turn, IoT4Ag and hosting labs learn from the participants' expertise and about their institutions. The residency duration and research agenda are structured to meet the participant and host lab needs.

Year 4 brought faculty member **L. Mei** from the **University of Maryland Eastern Shore** UMES) to work with Penn IoT4Ag faculty member P. Arratia for 3.5 weeks starting May 17, 2024. Mei brought a UMES undergraduate who spent time learning from the Arratia and Turner groups. Mei

and Arratia were successful at putting together a proposal for Mei to gain access to a high-performance computing cluster necessary for her work. Starting July 1, a second faculty member, **M. Noufal** from **Hampton University**, joined IoT4Ag as part of this program, and was also hosted by Arratia. Noufal's primary focus was using the Singh Center for Nanotechnology's lithography instruments to advance his research on photonics and develop new expertise in microfluidics (optofluidics) for plant nutrient detection. This project was conceived during Noufal's visit at Penn and combines his expertise in photonics and Arratia's expertise in microfluidics. Noufal completed his 4-week residency with much enthusiasm for returning with Hampton students (this exchange will be elaborated on in the Year 5 report).

This MSI-HBCU Partners Network Program, which is in an early-stage pilot phase, aims to **catalyze long term individual and institutional partnerships** in **research** and **education**. From this summer's exchanges, we are eager for the next partner exchanges and will work on program adjustments that we think will make the program better. We anticipate this program will be valuable for implementation at other IoT4Ag institutions, and more broadly among other ERCs. A Year 5 activity will be to reflect on and formalize practices that should increase the benefits of the program for both the visitors and hosts. In the longer timeframe, we will share best practices for the exchanges themselves and for the sustaining of the partnerships and cultivation of network synergies.

Assessment: In Section 4E. Engineering Workforce Development, we describe our assessment activities for our EWD-DCI portfolio, which includes guidance from our EWD-DCI Advisory Board, Evaluation from Boyce, ASU, and yearly joint EWD-DCI IoT4Ag E^3 milestones and a 10-year EWD-DCI milestone chart prepared to serve our EWD and DCI logic models (**Fig. 4F.6** at the end of the document).

Diversity and Culture of Inclusion in Yrs 6-10: IoT4Ag E^3 Development and Implementation: In Years 6-10, the Center will follow our guiding principles (see **Section 4E. Engineering Workforce Development)** to create and sustain a diverse and innovative IoT4Ag E^3 Portfolio along the continuums of uniqueness, readiness, and anticipated lifespan. We will execute upon and pursue funding to support the scaling and sustainability of our signature initiatives. Here, we highlight DCI-led components of the Year 6-10 Action Plan for the IoT4Ag E^3 Portfolio; IoT4Ag DCI gives special attention to the ***people*** part of our **Empowering People** portfolio.

In Year 5, we will perform an **in-depth analysis** of our **broadening participation** and **inclusivity activities**. This effort will start with one-on-one discussions with Advisory Board members who are in positions to guide our development of an effective and cohesive, actionable plan. The plan will seek to define the priority activities with **potential for the highest Center-wide impact** on broadening participation and inclusivity **within the Center** *and* for the **Center's externally facing activities across the foundational components**. The plan will review **strategic partnership development** and **strengthening** with organizations a) **within** our **Center institutions**, b) with **other ERCs**, and c) with **external organizations** that have deep expertise around inclusion in STEM and in Ag-Tech disciplines as well as in education, research, and innovation more broadly.

Within our IoT4Ag institutions, we will assess whether we are leveraging the expertise of colleagues and resources at our home institutions (e.g., diversity and recruitment, media/external communications/external relations, foundations and grant-focused offices) and determine what next steps align with the Center's strategic plan. For inter-ERC partnerships, we are testing shared booth sponsorship (with ERCs NEWT, PATHS-UP and ATP-BIO) at the Society for the

Advancement of Chicanos/Hispanics and Native Americans in Science NDiSTEM Conference (October 2024). For current external partnerships, we will assess how they align with our guiding principles and map onto IoT4Ag E^3. We will continue to build on the active, prioritized partnerships to solidify and sustain them (e.g., MANRRS, 4-H, our first MSI-HBCU Partners Network faculty and their institutions, Latino Farmers Alliance). For early-stage partners, we will establish timelines and anticipated outputs for helping us prioritize our investments, while also recognizing that building trust, and working with individuals across disciplines in a diversity of organizational types and in a range of sectors, is often slower work that requires risk taking, creativity, patience with non-linear progress, and appreciation for the benefits, and constraints, of equitable collaboration in a complex world. This broadening participation and inclusivity analysis will result in a plan for **prioritized efforts** for **strategic implementation** of our **capacity** to increase the **quality** of our **outcomes** throughout the Center in Years 6-10.

For the DCI-led Signature Initiative **Pathway to PhD Program (PPP)**, we will create new, professionally produced, online materials that will allow for asynchronous dissemination of the program's content over IoT4Ag's YouTube Channel, which will be accessible at anytime from anywhere. We will identify administrative and funding infrastructure that will creatively and sustainably scale PPP's high touch mentoring and workshopping of participant writing samples.

For the DCI-led **MSI-HBCU Partners Network**, we will build a robust partner network, with flexible yet formalized practices for adoption by other institutions. With our MSI-HBCU partners, we will find ways to sustain and grow our collaborative work. This program is in the pilot stage, with 2024 being the first summer residency. In Years 6-10, we will simultaneously build and better the program on shorter timescales, and, for the longer timescales, pursue pathways for cultivating the network synergies and sustaining the individual and institutional partnerships. In summary, in Years 6-10, DCI will continue to be an essential component for the implementation of the IoT4Ag E^3 Portfolio (see **Section 4E. Engineering Workforce Development)** and more generally for the success of our Center-wide programs, products, and *people*.

RECRUITMENT/RETENTION, MENTORING, and TRAINING STRATEGIES

Our IoT4Ag E^3 Portfolio, with DCI-led programs described above and the EWD-led programs described in **Section 4E. Engineering Workforce Development**, works as a unified scaffold to recruit participants into the Center, as program participants, users of Center resources and products, trainees, collaborators, and partners, and to recruit individuals more broadly into STEM and Ag-Tech academic and career pathways. Once engaged with the Center, IoT4Ag E^3 also provides the fabric for community building, knowledge flow, research acceleration and the innovation spark that makes the Center more than its sum of individual components. Mentoring and training are elemental for all IoT4Ag's foundational components and for the IoT4Ag E^3 Portfolio. The Center has robust mechanisms through our Assessment team and Advisory Boards and Councils, and through NSF-ERC reporting and review processes, to identify problems related to recruitment, retention, mentoring and training and to consider and implement best fit solutions that increase IoT4Ag's implementation of its strategic plan. Purdue, UC Merced, UF, and Penn also have offices that support research training (e.g., Environmental Health and Radiation Safety), teaching and learning, diversity and recruitment, student affairs, wellness, etc., that our Center members and leadership teams use as resources for recruitment, retention, mentoring and training.

ENGAGEMENT of URM at all LEVELS

IoT4Ag Diversity Statistics (ERCWEB Figs. 6-9 and Tables 12 and 13): The Center exceeds national diversity percentages for all U.S. Citizen/Permanent Resident academic categories for which there is a national benchmark percent (**ERCWEB Table 12**; i.e., faculty, doctoral, non-REU undergrads), except for domestic master's students. Note that IoT4Ag had only N=6 Master's students during the Year 4 (and for Master's students identifying as URM and Hispanic/Latino, IoT4Ag's N=1 in each of these categories exceeds their respective national % statistics). Demographic categories for small numbers (including the Center Total Postdocs (N=3)) serve as starting points for describing URM engagement but must be interpreted with caution; interpretation of small numbers is also affected by intersectionality of identities (e.g., is it a single individual who identifies as a URM, Latina Woman, or do these numbers reflect 2 or 3 distinct people?).

The REU category in this table does not have a national percent for benchmarking; however we are encouraged that the Center's REU student population (N=28) exceeds the benchmark % for national (non-REU) undergrads substantially in the gender (Center 42.9% v National 24.8%) and URM (Center 17.9% v National 5.9%) categories, and is slightly above for the disabilities category (IoT4Ag's REU Hispanic category is below the national percentage such that having an additional 2 of the 28 REU students identifying as Hispanic would be needed to exceed the 19.2% national percent). We call out the REU category because it is one in which there is greater Center control over promotion of the program and of the resulting selection from a national pool of talent, which is often larger than for the other academic categories. Above, in describing our Increasing Visibility of IoT4Ag, we described expansion of our REU promotion to reach pools of diverse students. Our REU student statistics support that we are recruiting from a diverse talent pool.

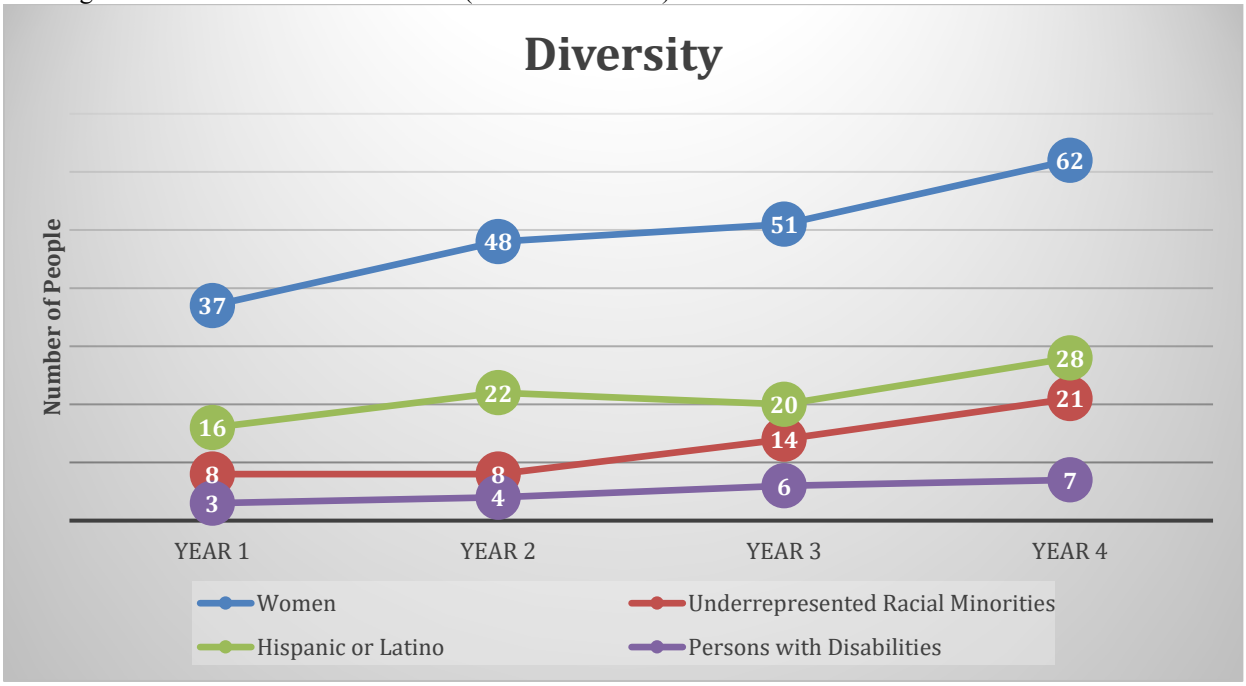
When IoT4Ag's domestic statistics are benchmarked against the 2023 peer-ERC domestic statistics, our Center has higher a) *graduate student* women (42.9% v 39.4%, **ERCWEB FIGURE 5**) and URM (17.1% v. 14.2%, **ERCWEB FIGURE 6**), b) *faculty* Hispanic (12.9% v 8.8%, **ERCWEB FIGURE 7**) and Disabilities (9.7% v 3.7%, **ERCWEB FIGURE 8**) statistics. IoT4Ag applauds the NSF ERC program's cultivation of diverse Center membership statistics that typically far exceed the national percentages, and we continue to prioritize broadening participation for our Center activities and membership.

Meaningful, inclusive engagement: Beyond the diversity classifications, IoT4Ag works toward engaging URMs, and all its members, in a Center culture that is intellectually, professionally, and personally rewarding and that embodies the vision that **agriculture** and **STEM academic**, **research**, and **career paths** are **exciting**, **welcoming**, and **full of opportunity.** In addition to the formal IoT4Ag E^3 programs and activities described here and in **Section 4E. Engineering Workforce Development**, the Center and its members initiate and participate in action that contributes to this vision. Examples showing the range and variety of inputs affecting the Center climate and culture of inclusion are: positioning earlier career faculty in roles that shape the Center (e.g., P. Chaudhari, Convergence Team; L. Yeo, DCI co-lead, D. Quinn, Testbed Lead), a faculty member's intentional, public acknowledgment of having a disability on a Center-wide panel, IoT4Ag faculty participation in diversity activities outside of their IoT4Ag roles, and IoT4Ag students AND non-IoT4Ag students being eager to contribute to IoT4Ag EXCITE, EDUCATE, and ENABLE outreach and mentoring activities. A few of the many student activities that could be listed here are delivering ACLAMO Cutebot workshops, hosting IoT4Ag campus tour and demos, serving as PPP mentors, participating in the IoT4Ag pitch contest and representing the

Center at the ERC Biennial meeting ERC-wide pitch contest, presenting an IoT4Ag pitch for a women's-URM Innovators Ignite event.

In addition, on the next page is a trend chart showing the IoT4Ag member diversity from Year 1 through Year 4.

Funding trend chart from Year 1 to Year 4 (Center-Generated)



RESPONSE TO SWOT

The section below responds to last year's NSF site visit SWOT.

Weaknesses:

- The SVT believes the Center's EWD and DCI efforts look disjointed and appear to be more opportunistic than strategic. This may be in part because of a lack of detailed goals and/or lack of interaction with the EWD and DCI Advisory Boards. It could also be that there are not sufficient funds allocated to these ERC Pillars. Some SVT members suggested reallocation of Center funds to support these activities.

RESPONSE:

Thank you for the comment. IoT4Ag took the SVT feedback seriously! In Year 4, IoT4Ag established a new Director of Education and Inclusivity position and hired Dr. Kristin Field, who has 11 years of experience leading education and inclusion programs for multi-PI NSF grants. In partnership with our advisory boards and in response to feedback from last year's NSF Site Visit, we undertook an evaluation of the structure, function, and integration of our EWD and DCI programs and activities to ensure intentionality and to deliver on our goals. Field led the Center in executing the strategic integration and implementation of IoT4Ag's Action Plan for EWD and DCI programs. We introduced the

IoT4Ag Empowering People Portfolio, we call for short, **IoT4Ag E^3** for EXCITE - Tech Meets Ag, EDUCATE for an Inclusive World, and ENABLE Professional Advancement (**Fig. 4F.1, bottom**), and we established a set of guiding principles to ensure the selection, creation, execution, and sustainability of our portfolio of programs and activities, as described above and in **Section 4E. Engineering Workforce Development**. We also formed a singular EWD-DCI advisory board that operates as one in meeting and providing IoT4Ag guidance.

Threats:

- The 2022 SVT suggested "[there was very limited interaction (almost null) with EWD Advisory Board and DCI Advisory Board. There appeared to be no coherent interactions across advisory boards.]" In response to this, the SVT recognizes the Center attempted to develop strategies, for this reporting year, to effectively engage these Boards. Having said this, the SVT believes the Center needs to re-think its approach. The highly qualified members of both Boards are eager to be active participants and help the Center achieve its EWD and DCI goals. The SVT would like to see a more detailed Board engagement plan.

RESPONSE:

Thank you for the comment. In response to the 2023 SVT report, we worked with our EWD and DCI boards to join these bodies, forming a single EWD-DCI Advisory Board. The Board met jointly in January, April, and July 2024. We have worked with the Board in establishing the IoT4Ag E^3 Portfolio along the continuums of uniqueness, readiness, and anticipated lifespan, and about the strategic collection of best-practice and case-study Signature Initiative programs for IoT4Ag EXCITE, EDUCATE, and ENABLE. We have responded to the Board's annual SWOT (July 2024) that will inform our Year 5 activities and contribute to our success in implementing IoT4Ag E^3. We continue to build on our engagement with the Board, having invited members to receive our weekly Center updates, and we will roll out a Dashboard in Year 5 to quickly see IoT4Ag E^3 progress and to be able to initiate engagement beyond the Board meetings. Within the IoT4Ag E^3 framework, we are tapping into the expertise and networks of individual Board members for EXCITE (Philadelphia School District-Fairmount Water Works Partnership and Year 6-10 plans) and for recruitment for EDUCATE programs, like the Pathway to PhD Program (PPP). Year 5 will deepen our participation with Board members around EDUCATE and ENABLE (e.g., community college and DCI-led programs, including the PPP and MSI-HBCU Partners Network Program).

Middle-Band Requirements:

- One concern raised by the previous SVT was the reliance of UC-Merced on diversity in representation within the Center. While this has improved, we believe there could be more progress in this area.

RESPONSE:

The diversity in representation among IoT4Ag's membership is not reliant on UC-Merced, and is represented across all four partner institutions, in line with NSF's expectations. The current representation, as of June 2024, of each partner institution compared to their total membership is in the table below. In the next year, as part of our new IoT4Ag E^3 Portfolio, we will conduct a deep analysis that defines the priority activities with potential for the highest Center-wide impact on broadening participation and inclusivity within the Center

and for the Center's externally facing activities across the foundational components. Implementation of this plan will accelerate our progress in Years 6-10 with respect to Diversity and Culture of Inclusion.

Institution	Woman	URM	Hispanic	Disability	Foreign
Penn	37%	18%	5%	0.0%	37%
Purdue	18%	0%	0%	0.0%	46%
UC Merced	39%	17%	33%	13%	25%
Florida	36%	4%	20%	5%	33%

- It is **imperative** during Year 4 that the Center identifies its overarching goals regarding diversity efforts and maps how its different components align with, take up, and remain accountable to these goals.

RESPONSE:

IoT4Ag follows the guiding principle that Diversity and Culture of Inclusion (DCI) truly underpins all foundational components. In Year 4, we rolled out the IoT4Ag Empowering People Portfolio: Excite-Educate-Enable (IoT4Ag E^3). Working in tandem with Engineering Workforce Development (EWD), we are implementing inclusive programs for diverse audiences under: a) EXCITE - Tech Meets Ag, which serves pre-college and broader public audiences; b) EDUCATE for an Inclusive World, which trains and mentors community college through postdoctoral audiences; and c) ENABLE Professional Advancement, which engages i) farmers, end-users, and other professionals connected to agriculture, Ag education, and technology development, and ii) professionals in education who influence students pursuing Ag and STEM pathways. As our response above stated, our Year 5 deep analysis of IoT4Ag E^3 activities through a diversity and inclusion lens, and the implementation of the resulting plan will focus our DCI effort. We will be able to optimize our capacity, which will lead to accelerated progress and enhanced quality of IoT4Ag E^3 outcomes with respect to Diversity and Culture of Inclusion in the upcoming years.

INPUTS & RESOURCES	ACTIVITIES	OUTPUTS	OUTCOMES		
			KNOWLEDGE SHORT-TERM	ACTION MEDIUM-TERM	IMPACTS LONG-TERM
•NSF funding and ERC program resources •Students, teachers, faculty, and staff and partner K-12 institutions, community colleges, and universities •Existing relationships with minority serving institutions (MSIs) and national organizations •Existing and new relationships with industry members, government and innovation partners, and the end-user community of growers joining our industry practitioner and Ag-systems advisory boards •Student Leadership Council •DCI advisory board members •NSF ERC Gen 4 Cohort and DCI focus group	EXCITE •Deliver IoT4Ag mission-driven, research-relevant K-12/general public-focused lessons, hands-on activities, demonstrations that reach underserved institutions or groups and/or those underrepresented in Ag sciences or STEM •Ensure IoT4Ag engagement with K-12 teachers and schools is inclusive of underserved institutions or groups and/or those underrepresented in Ag sciences or STEM •Develop partnerships aligned with the above activities EDUCATE •Support EWD-led EDUCATE programs' efforts to serve community college- to graduate-level students and postdocs from a diverse range of backgrounds and institutions •Pathway to PhD Program (PPP) •Minority-Focused Events/Outreach ENABLE •Support EWD-led ENABLE programs' efforts to serve growers, Ag professionals, practitioners, organizations having a diverse range of backgrounds, interests, and missions •Minority Serving Institution - Historically Black Colleges and Universities (MSI-HBCU) Partners Network Program	EXCITE •Lesson plans and activities for formal and informal education that are easily teachable, flexible, engaging for diverse audiences •IoT4Ag-based lesson plans/activities being used in underserved schools to broaden participation of groups underrepresented in Ag sciences and STEM; Underrepresented students engaged by IoT4Ag teams in their classrooms or at IoT4Ag universities •Partnered activities, events, projects, dissemination EDUCATE •Inclusive promotion of EDUCATE opportunities (e.g., REU, ITEX, student leadership roles); Diversity of speakers and topics for EDUCATE programs; Dissemination of and encouraged participation in Center- and partner-organized inclusivity events; Resources and expertise for broadening participation and inclusivity topics/challenges •Intensive online workshop and continued mentorship: information for success for applying to and securing funding for graduate school for Ag sciences & STEM fields; mentees paired with PhD+-level mentors for hands-on workshopping of application materials that continues ~6 weeks •Center- and external organization-led activities, events, workshops, projects, exhibit booths ENABLE •Talks, workshops, extensions programs, crop advisor certification, tech demos, field days, exhibit booths, listening-feedback sessions in diverse, inclusive forums •MSI-HBCU faculty in-residency in IoT4Ag research labs; MSI-HBCU student participation as appropriate	EXCITE •Understanding of best practices - What lessons/activities work in different settings, Who to train & How to deploy •RET Program: develops IoT4Ag lesson plans, enables teachers to develop, pilot, teach materials to meet their students' needs & curricular standards •Understanding between IoT4Ag and partners of what to collaborate on & how to work together EDUCATE •Underrepresented students & their mentors/organizations know about IoT4Ag opportunities; Center members perceive IoT4Ag activities are inclusive; Center supports culture of engagement and participation by all; Early identification of DCI-related problems •Mentees (open to all who sign up) understand the process of applying to and funding graduate degrees in the U.S.; mentors (provided training before the workshop) practice mentoring, writing, communication skills •Personal interactions, knowledge-exchange, resource sharing that aims to broaden participation in IoT4Ag's activities and more generally for Ag sciences & STEM ENABLE •Growers, Ag practitioners and professionals know about IoT4Ag's mission, research, opportunities for participation & partnership; IoT4Ag learns from a diversity of stakeholders •Exchange of research ideas and resources; foundation-building for collaborative research; testing of program's administrative structure	EXCITE •Diverse IoT4Ag teams and partners lead lesson plans/activities; Lessons/activities made web-accessible to all educators and learners •Educators continue to use and build upon IoT4Ag lessons; IoT4Ag supports their efforts (materials, expertise) •Development of strategic evolving portfolio of activities, events, projects, partners aligned w/ IoT4Ag and broadening participation in Ag sciences and STEM EDUCATE •IoT4Ag continues work to support: Applications to Center programs reflect talent from a diversity of backgrounds; Center members participate in Center activities & feel supported, respected, stimulated by and rewarded by their contributions to research, innovation, education activities; Interventions when challenges arise for better broadening participation & inclusivity strategies •IoT4Ag continues work to promote this program broadly; to test and evaluate ways to scale it for the increasing interest & participation without losing its unique components •Foster and strengthen participation of individuals from underrepresented groups in Center activities, and early partnerships with individuals & organizations supportive of ENABLE •Enable individual practitioners to learn about and use new research and products/systems for farming; Foster and strengthen diverse & equitable participation and early partnerships •Pursue resources to sustain individual faculty-host/IoT4Ag continued collaboration; Develop formal, adaptable program structure: practices for increasing participation, guides to ensure equitable and rewarding implementation	EXCITE •Diverse K-12 and general public audiences learn how tech can meet the needs of Ag & connects to food, energy, and water security; they feel agriculture and STEM academic research and career paths are exciting, welcoming, and full of opportunity; IoT4Ag trainees build science communication skills •The number of classrooms serving underrepresented students exposed to and excited by precision Ag and food-energy-water sustainability increases •Pedagogical tools equitably used and disseminated by external organizations; IoT4Ag is seen as an inclusive resource for Ag-Tech education and outreach EDUCATE •Center alums represent groups who have been underrepresented and/or advance the cultivation of broader participation of these groups in next academic and career steps; strong institutional collaborations to continue broadening participation in Ag, STEM, and adjacent disciplines •Increased accessibility of knowledge about and skills for pursuing advanced degrees in STEM and Ag-Tech; experiential training for mentors to work with, and increase opportunities for, a diversity of individuals - experience that is transferable into their next career/leadership positions to continue to broaden participation in their professional arenas •Partnerships for advancing inclusive practices in Ag-Tech and STEM ENABLE •Partnerships for advancing inclusive participation & practices in Ag-Tech and STEM •Catalysis of long-term individual and MSI-HBCU-R1 institutional partnerships in research and education

Figure 4F.5 DCI Logic Model.

ERCWEB TABLE 12: DIVERSITY STATISTICS FOR ERC FACULTY AND STUDENTS

Table: Diversity Statistics for ERC Faculty and Students							
	U.S. Citizens or Permanent Residents						
	Leadership Team [4]	Faculty [5]	Postdocs	Doctoral Students	Masters Students	Undergrad Non-REU	REU Students
Center Total	**22**	**31**	**3**	**29**	**6**	**25**	**28**
Women							
Category Total	8	9	1	14	1	9	12
Center Percent	36.4%	29.0%	33.3%	48.3%	16.7%	36.0%	42.9%
National Percent [1][2]	N/A	20.0%	N/A	31.7%	26.8%	24.8%	N/A
Underrepresented Racial Minorities							
Category Total	2	2	1	5	1	3	5
Center Percent	9.1%	6.5%	33.3%	17.2%	16.7%	12.0%	17.9%
National Percent [1][2]	N/A	3.2%	N/A	5.6%	5.3%	5.9%	N/A
Hispanic or Latino							
Category Total	2	4	1	3	1	5	4
Center Percent	9.1%	12.9%	33.3%	10.3%	16.7%	20.0%	14.3%
National Percent [1][2]	N/A	3.9%	N/A	9.7%	11.5%	19.2%	N/A
Persons With Disabilities							
Category Total	1	3	0	1	0	1	2
Center Percent	4.5%	9.70%	0.0%	3.4%	0.0%	4.0%	7.1%
National Percent [1][2] [3]	N/A	7.4%	N/A	3.5%	3.5%	5.2%	N/A

	Foreign (Temporary Visa Holders)					
	Leadership Team [4]	**Faculty [5]**	**Postdocs**	**Doctoral Students**	**Masters Students**	**Undergrad Non-REU**
Center Total	**6**	**2**	**7**	**34**	**9**	**5**
Women						
Category Total	1	1	2	10	1	1
Center Percent	16.7%	50.0%	28.6%	29.4%	11.1%	20.0%
National Percent [1][2]	N/A	24.4%	N/A	27.3%	31.2%	24.6%
Underrepresented Racial Minorities						
Category Total	0	0	1	3	0	0
Center Percent	0.0%	0.0%	14.3%	8.8%	0.0%	0.0%
National Percent [1][2]	N/A	N/A	N/A	N/A	N/A	N/A
Hispanic or Latino						
Category Total	0	0	1	6	1	2
Center Percent	0.0%	0.0%	14.3%	17.6%	11.1%	40.0%
National Percent [1][2]	N/A	N/A	N/A	N/A	N/A	N/A
Persons With Disabilities						
Category Total	0	0	0	0	0	0
Center Percent	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
National Percent [1][2] [3]	N/A	7.4%	N/A	3.5%	3.5%	5.2%

	Citizenship Not Reported					
	Leadership Team [4]	Faculty [5]	Postdocs	Doctoral Students	Masters Students	Undergrad Non-REU
Center Total	**1**	**1**	**1**	**2**	**0**	**2**

Women						
Category Total	1	0	0	1	0	0
Center Percent	100.0%	0.0%	0.0%	50.0%	0	0.0%
National Percent [1][2]	N/A	N/A	N/A	N/A	N/A	N/A

Underrepresented Racial Minorities						
Category Total	0	0	0	0	0	0
Center Percent	0.0%	0.0%	0.0%	0.0%	0	0.0%
National Percent [1][2]	N/A	N/A	N/A	N/A	N/A	N/A

Hispanic or Latino						
Category Total	0	0	0	0	0	0
Center Percent	0.0%	0.0%	0.0%	0.0%	0	0.0%
National Percent [1][2]	N/A	N/A	N/A	N/A	N/A	N/A

Persons With Disabilities						
Category Total	0	0	0	0	0	0
Center Percent	0.0%	0.0%	0.0%	0.0%	0	0.0%
National Percent [1][2] [3]	N/A	N/A	N/A	N/A	N/A	N/A

Table: Summary: Count of ERC Personnel												
Faculty	**Community College RET**	**K-12 Teachers**		**Postdocs**	**Students**					**Young Scholars**	**Other [6]**	**Total**
		RET	**Non-RET**		**Graduate**		**UG Non-REU**		**REU**			
					Doctoral	**Masters**						
34	0	6	0	11	65	15	32		28	0	23	202

[1] The national percentages for Underrepresented Racial Minorities and Hispanic or Latino are only available for U.S. citizens and permanent residents (Source: ASEE).

[2] Most recent national percentages available are from the following years: Women - 2023, Underrepresented Racial Minorities - 2023, Hispanic or Latino - 2023, and Persons with Disabilities - 2008. (Source: ASEE).

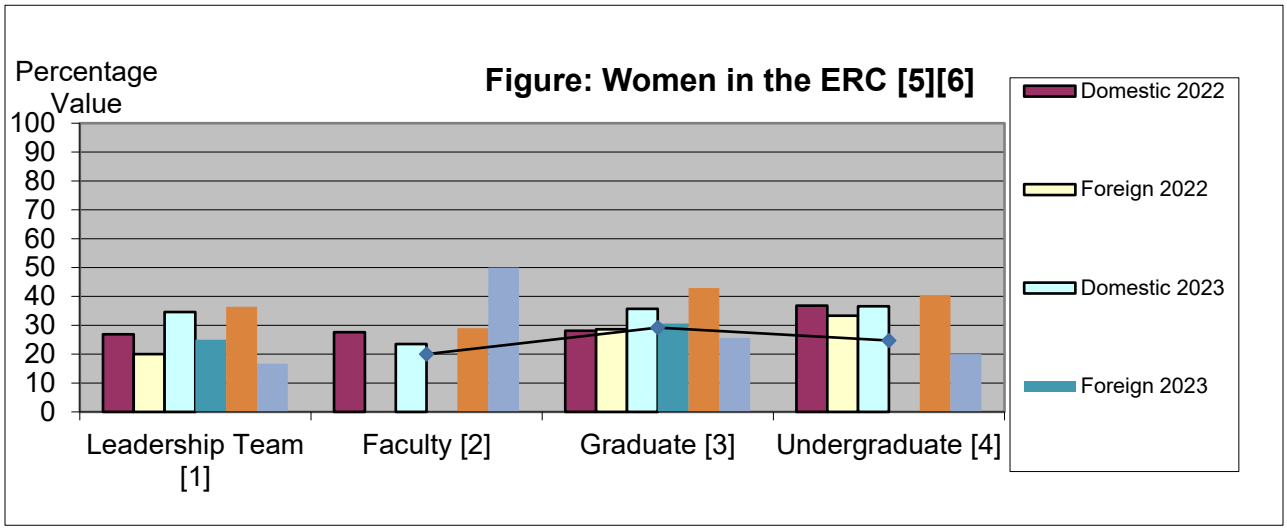
[3] The national percentages for Persons with Disabilities are for all persons, regardless of citizenship. The national percentages for Doctoral students with disabilities and Masters students with disabilities are from the national percentages for Graduate students (Masters and Doctoral students combined) (Source: ASEE).

[4] Leadership Team includes Directors, Research Thrust Leaders, Engineering Workforce Development Program Leaders, Innovation Ecosystem Program Leader, Administrative Director, Staff, Diversity and Culture of Inclusion Program Leaders and Student Leaders.

[5] Faculty includes Programmatic Personnel - Senior Faculty, Programmatic Personnel - Junior Faculty and Programmatic Personnel - Visiting Faculty.

[6] Other includes Innovation Ecosystem Program Leader, Administrative Director, Staff, Programmatic Personnel - Industry Researchers, Programmatic Personnel - Other Visiting College Students and Programmatic Personnel - Staff.

ERCWEB FIGURE 5: WOMEN IN THE ERC



Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2023 [6]	N/A	20%	29.2%	24.7%
All ERC's 2023 (Domestic)	47.5%	32.9%	39.4%	46.3%
All ERC's 2023 (Foreign)	45%	17.3%	33.1%	37%
Domestic Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	36.4%	29%	42.9%	40.4%
Foreign Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	16.7%	50%	25.6%	20%

[1] Leadership Team includes Directors, Research Thrust Leaders, Engineering Workforce Development Program Leaders, Innovation Ecosystem Program Leader, Administrative Directors, Staff, Diversity and Culture of Inclusion Program Leaders and Student Leaders.

[2] Faculty includes Programmatic Personnel - Senior Faculty, Programmatic Personnel - Junior Faculty and Programmatic Personnel - Visiting Faculty.

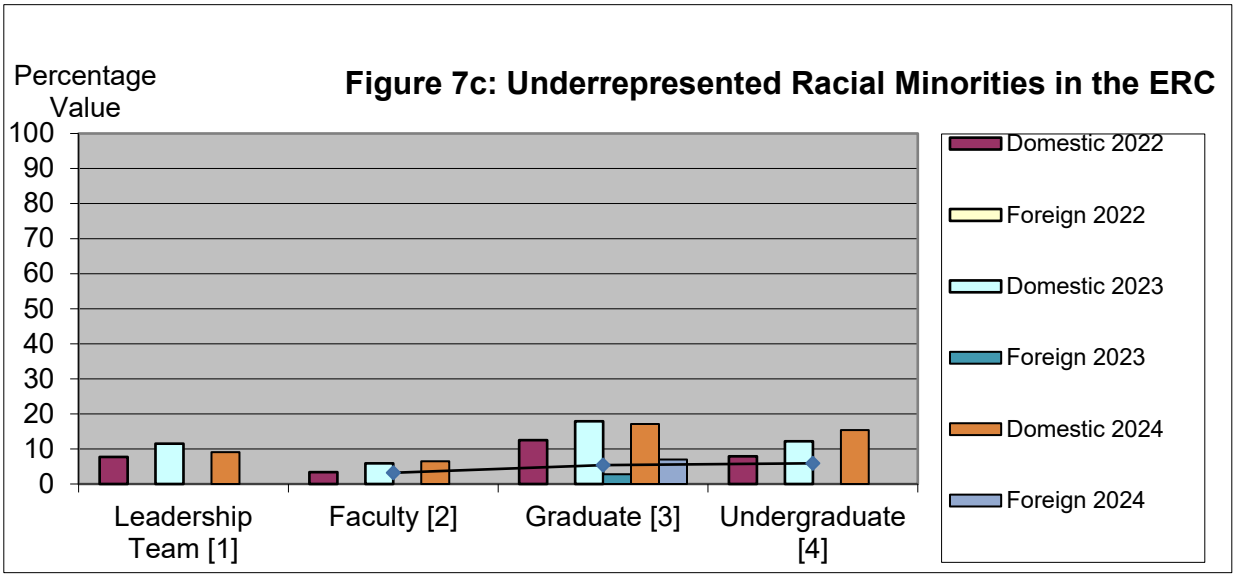
[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

[5] The number of personnel for whom gender was not reported are not excluded from the percentage calculations.

[6] National Engineering Averages for faculty are for U.S. citizens only (Source: ASEE).

ERCWEB FIGURE 6: UNDERREPRESENTED RACIAL MINORITIES IN THE ERC



Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2023 [5]	N/A	3.2%	5.4%	5.9%
All ERC's 2023 (Domestic)	13.1%	9.5%	14.2%	17.4%
All ERC's 2023 (Foreign)	7.5%	3.8%	7%	7.4%
Domestic Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	9.1%	6.5%	17.1%	15.4%
Foreign Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	0%	0%	7%	0%

[1] Leadership Team includes Directors, Research Thrust Leaders, Engineering Workforce Development Program Leaders, Innovation Ecosystem Program Leader, Administrative Directors, Staff, Diversity and Culture of Inclusion Program Leaders and Student Leaders.

[2] Faculty includes Programmatic Personnel - Senior Faculty, Programmatic Personnel - Junior Faculty and Programmatic Personnel - Visiting Faculty.

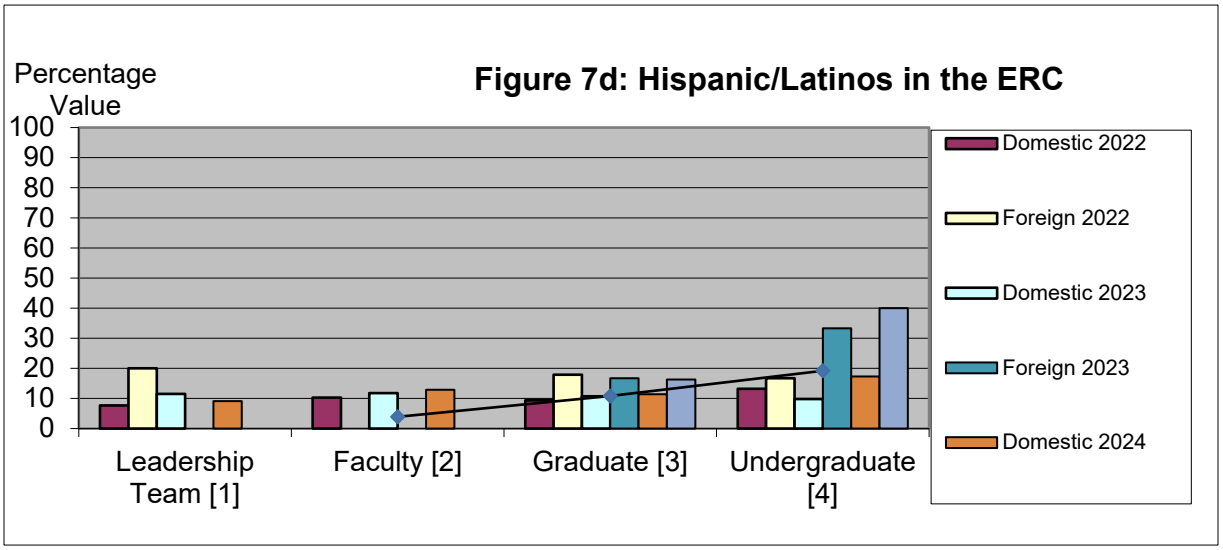
[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

[5] The number of personnel for whom gender was not reported are not excluded from the percentage calculations.

[6] National Engineering Averages for faculty are for U.S. citizens only (Source: ASEE).

ERCWEB FIGURE 7: HISPANIC / LATINOS IN THE ERC



Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2023 [5]	N/A	3.9%	10.8%	19.2%
All ERC's 2023 (Domestic)	13.1%	8.8%	15.3%	24.1%
All ERC's 2023 (Foreign)	10%	13.5%	11.8%	18.5%
Domestic Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	9.1%	12.9%	11.4%	17.3%
Foreign Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	0%	0%	16.3%	40%

[1] Leadership Team includes Directors, Research Thrust Leaders, Engineering Workforce Development Program Leaders, Innovation Ecosystem Program Leader, Administrative Directors, Staff, Diversity and Culture of Inclusion Program Leaders and Student Leaders.

[2] Faculty includes Programmatic Personnel - Senior Faculty, Programmatic Personnel - Junior Faculty and Programmatic Personnel - Visiting Faculty.

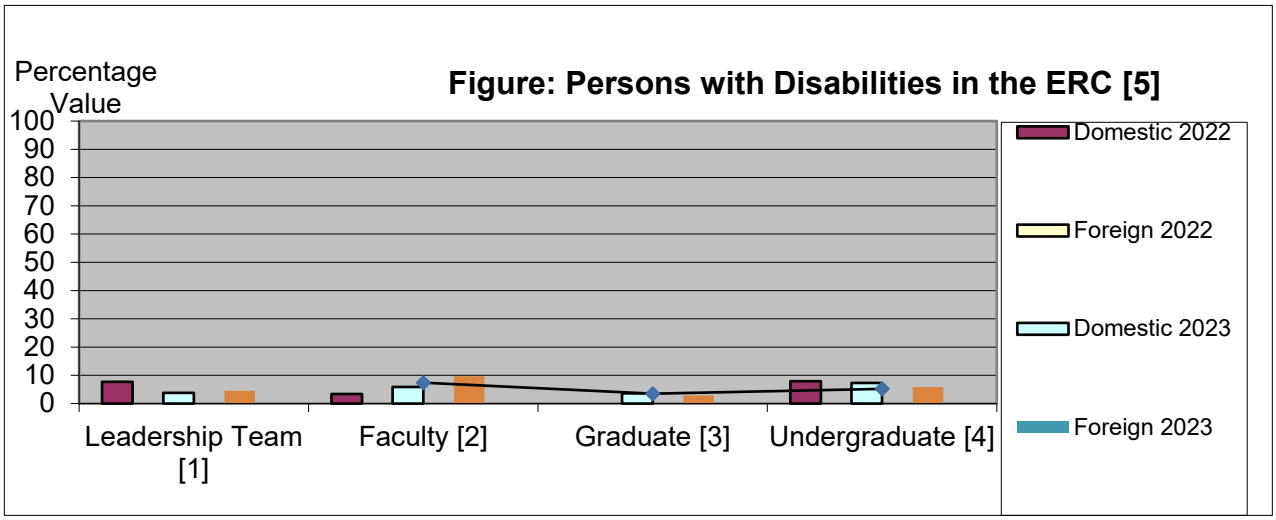
[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

[5] The number of personnel for whom gender was not reported are not excluded from the percentage calculations.

[6] National Engineering Averages for faculty are for U.S. citizens only (Source: ASEE).

ERCWEB FIGURE 8: PERSONS WITH DISABILITIES IN THE ERC



Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2008 [6]	N/A	7.4%	3.5%	5.2%
All ERC's 2023 (Domestic)	5.5%	3.7%	5.1%	5.4%
All ERC's 2023 (Domestic)	0%	0%	0%	0%
Domestic Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	4.5%	9.7%	2.9%	5.8%
Foreign Percentage for NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) 2024	0%	0%	0%	0%

[1] Leadership Team includes Directors, Research Thrust Leaders, Engineering Workforce Development Program Leaders, Innovation Ecosystem Program Leader, Administrative Directors, Staff, Diversity and Culture of Inclusion Program Leaders and Student Leaders.

[2] Faculty includes Programmatic Personnel - Senior Faculty, Programmatic Personnel - Junior Faculty and Programmatic Personnel - Visiting Faculty.

[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

[5] The number of personnel for whom gender was not reported are not excluded from the percentage calculations.

[6] National Engineering Averages for faculty are for U.S. citizens only (Source: ASEE).

ERCWEB TABLE 13: CENTER DIVERSITY, BY INSTITUTION

Table: Center Diversity, by Institution						
Institution	**Women [1]**		**Underrepresented Racial Minorities [1] [2]**		**Hispanics [1]**	
	Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Lead Institution						
University of Pennsylvania	14	37%	7	18%	2	5%
Core Partners						
Purdue University	3	18%	0	0%	0	0%
University of California, Merced	7	39%	3	17%	6	33%
University of Florida	9	36%	1	4%	5	20%
Collaborating Institutions						
Arizona State University	4	100%	2	50%	1	25%
University of Maryland Eastern Shore	0	0%	1	100%	0	0%
Non-ERC Institutions Providing REU Students						
California Polytechnic State University San Luis Obispo	1	50%	0	0%	0	0%
Grinnell College	0	0%	1	100%	0	0%
Illinois Institute of Technology	0	0%	0	0%	0	0%
Merced College	1	50%	0	0%	2	100%
North Carolina State University at Raleigh	1	100%	0	0%	0	0%
Northeastern University	0	0%	0	0%	0	0%
Northwestern University	1	100%	0	0%	0	0%
Pennsylvania State University-Main Campus	0	0%	0	0%	0	0%
Princeton University	0	0%	1	100%	0	0%
Santa Clara University	0	0%	0	0%	0	0%
Santa Fe College	0	0%	1	50%	0	0%
Stevens Institute of Technology	1	100%	0	0%	0	0%
Swarthmore College	1	100%	0	0%	0	0%
Syracuse University	0	0%	1	100%	0	0%
The University of Texas at Dallas	1	100%	0	0%	0	0%
The University of Texas at El Paso	0	0%	0	0%	1	100%
University of Illinois at Urbana Champaign	1	100%	0	0%	0	0%
University of Maryland Baltimore County	1	100%	1	100%	0	0%
University of Pittsburgh	0	0%	0	0%	0	0%
University of Puerto Rico at Humacao	1	100%	0	0%	1	100%
University of Tennessee Martin	1	100%	0	0%	0	0%
University of Texas at Austin	1	100%	0	0%	0	0%
Villanova University	0	0%	0	0%	0	0%

Institution	Women [1]		Underrepresented Racial Minorities [1] [2]		Hispanics [1]	
	Number	Percent	Number	Percent	Number	Percent
Precollege Partners						
Kensington High School	0	0%	0	0%	1	100%
Lankenau Environmental Science High School	2	100%	2	100%	0	0%
Science Leadership Academy at Beeber	1	50%	1	50%	0	0%
W.B. Saul High School of Agriculture	0	0%	1	100%	0	0%

[1] - This data includes U.S. Citizens and Legal Permanent Residents only.

[2] - Underrepresented Racial Minorities is a sum of all personnel entered in the following categories: American Indian or Alaska Native, Black or African American, Native Hawaiian or Other Pacific Islander, or More than one race reported, minority.

4G. INNOVATION ECOSYSTEM

GOALS, ORGANIZATION, AND STATEGIES

The goal of the Innovation Ecosystem (IE) foundational component is to engage a community of IoT4Ag stakeholders working together to enhance the capacity for innovation and create new ways for delivering value for food, energy, and water security. The innovation ecosystem ensures transfer of knowledge, technology, and workforce from university to market via entrepreneurship and commercialization by industry partners. As a center, we have learned that adoption of new technologies by growers is a very long, slow process. Because of high seasonal variability, low profit margins, and long design-loop cycles (e.g. an entire year), growers are quite risk averse. It takes a long time for a producer to learn about and then build trust and confidence in any new technologies or practices. Grower interest, understanding, and adoption is typically built through a trusted network of crop advisors, extension agents, or a crop association. In the Ag industry, relationships and trust are critical. Compared to many other ERCs, these nuances provide IoT4Ag unique opportunities and challenges for tech adoption.

To address the unique tech adoption pipeline for Ag technologies, the IoT4Ag innovation ecosystem is structured with two external bodies: (1) the typical industrial/practitioner advisory board (IPAB) comprising industry, venture, and non-profit innovation partners; and (2) unique to IoT4Ag, an agricultural systems advisory board (ASAB) comprising the end-use grower community (producers, crop consultants, associations, extension agents) and state Ag departments. The two bodies balance "tech push" vs. "industry pull," provide valuable insight, and guide the direction of Center research, workforce development, and diversity & culture of inclusion activities (**Fig. 4G.1**).

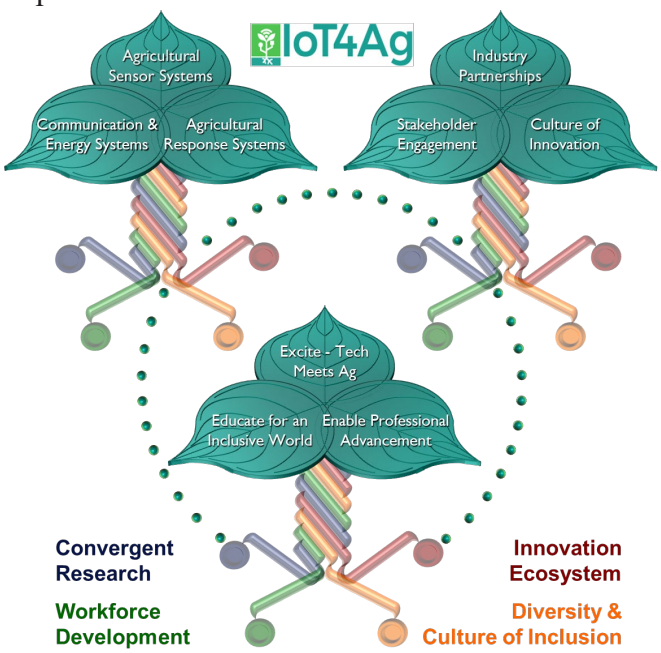


Figure 4G.1 Summary of integrated IoT4Ag thrusts and programmatic axes and their relationship to the four NSF Gen-4 ERC Foundational Components.

Efforts for the Innovation Ecosystem fall along three primary axes (**Fig. 4G.1**):

- **Culture of Innovation:** Nurturing innovation ecosystem
  - **Lead:** David Arnold, Co-PI and Innovation Ecosystem Director / Strategic Partnerships and Innovation (UF)
  - **Counsel:** University Participants / Center Leadership
- **Industry Partnerships:** Developing industry partner relations
  - **Lead:** Steven Weiner, ILO and Tech Transfer Director (Penn)
  - **Counsel:** Industry & Practitioner Advisory Board (IPAB)
- **Stakeholder Engagement:** Engaging end users
  - **Leads:** Katie Stofer and Sebastian Galindo (UF)
  - **Counsel:** Ag Systems Advisory Board (ASAB) and others

IoT4Ag has put into practice a process for integrative project management, with a yearly cadence of project definition – design – development – deployment that allows for evaluation, assessment, and revision of our plans and practices (see **Section 4D. Convergent Research**). The IPAB and ASAB are essential partners in this process, which begins with providing valuable insight and guidance in project definition and system requirements, i.e., in understanding the concrete agricultural problems and needs that our technology solutions must address (e.g. specific crop stresses, threats, and intervention options) and the constraints that those solutions will need to satisfy (e.g. interoperability with existing farm equipment and infrastructure, compatibility and ease of integration with farming practices, cost constraints). Early and continuous input from end stakeholders is especially important. The engagement spans the lifecycle of our research through system deployment and the transfer of knowledge, technology, and a diverse workforce, bringing together programs from all four foundational components. The processes are designed to ensure that IoT4Ag pursues research that has a clear value proposition for industry and that is well-suited for commercialization and, ultimately, adoption by the farming community.

The IE component defines a yearly roadmap (**Fig. 4G.2**) and sets annual (described below for Year 4) and 10-year milestones (**Fig. 4G.3**) deliberately designed to realize our long-term goals of stakeholder engagement, culture of innovation, and industry partnerships through multiple layered activities. This roadmap illustrates our annual cadence of project ideation, execution, and refinement as well as strategic interactions with the other center foundational components.

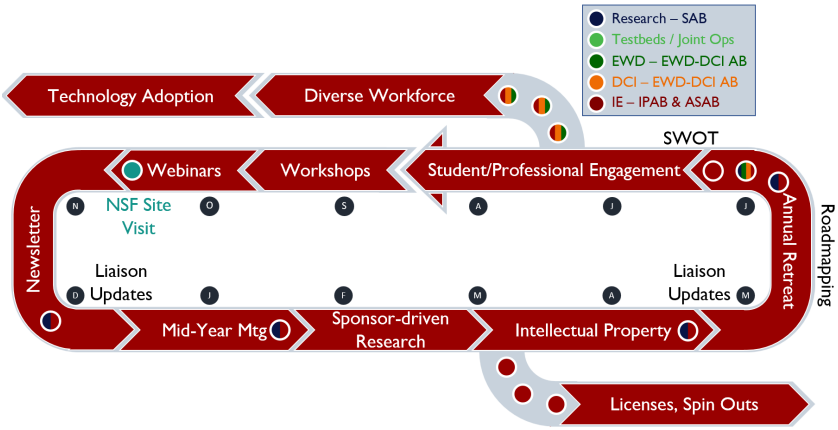


Figure 4G.2 Innovation Ecosystem Roadmap describing the annual cadence for engagement with external stakeholders and the other IoT4Ag pillars.

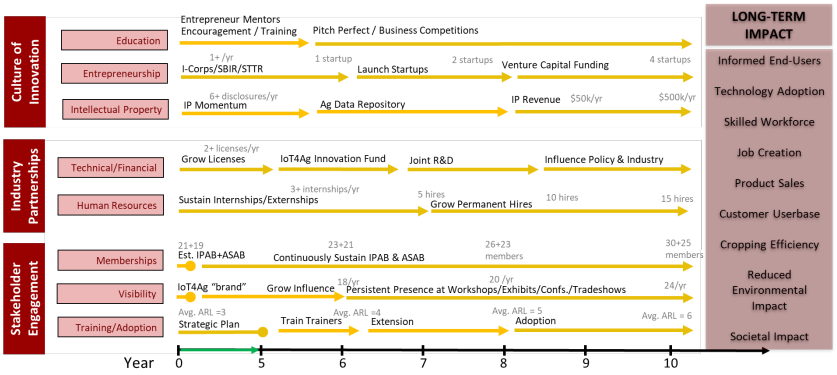


Figure 4G.3 Innovation Ecosystem 10-Year Milestone Chart describing the short-, medium-, and long-term goals for stakeholder engagement,

Our short-, medium-, and long-term goals are illustrated in the 10-year milestone chart (**Fig. 4G.3**) with focused KPIs in each of the three IE areas: culture of innovation, industry partnerships, and stakeholder engagement.

Culture of Innovation Strategy: Through ongoing interaction with our faculty, students, staff, industry, government and outside stakeholders, we are working to build a vibrant innovation ecosystem. Our culture of innovation strategy encompasses:

- Educating members about and keeping our entire team well informed (reminded) about the goal of the ERC to transition technology to industry
- Educating members about and encouraging and rewarding intellectual property generation (patents, copyrights, datasets)
- Engaging entrepreneurship mentors
- Facilitating idea competitions (Perfect Pitch, Big Ideas) and training (I-Corps)
- Leveraging our university tech-transfer offices
- Actively seeking input for improvement in all aspects of the IoT4Ag Center, followed by actionable changes (continuous process improvement)

Industry Partnerships Strategy: Our goal is to have a robust industrial engagement spanning the entire value chain of IoT for Agriculture. Our industry partnerships strategy encompasses:

- Sustaining a vibrant and engaged Industrial Practitioner Advisory Board (IPAB) targeting ~20-25 organizations with businesses in:
    - Robotics
    - Sensors
    - Remote sensing/imaging
    - Mobile power/energy
    - Data networking and communication
    - IoT data aggregation/platform
    - Data analytics, AI, and machine learning
    - Ag systems integrators
- Communicating persistently via our Industry Liaison Officer (Steven Weiner), Strategic Partner and Innovation Director (David Arnold), and Administrative Director (Bob Brier).
- Maintaining a members-only section of the webpage
- Adopting best practices from the ILO/SPI ERC working group
- Facilitating university / industry knowledge and personnel exchanges
    - Recurring technical meetings between university project teams and IPAB mentors
    - Center meetings with poster sessions and social interactions
    - Student internships; industry externships
    - Industry/university technical collaboration on our agriculture testbeds
- Offering favorable IP licensing terms

Stakeholder Engagement Strategy: End-user engagement is critical for engineering and technology development. Our vision is across-the-board stakeholder engagement.

- Establishing the Ag Systems Advisory Board (ASAB) comprising non-fee-paying producers, crop consultants, grower associations, and extension specialists, targeting ~20 individuals representing their constituencies.
- Facilitating cross-disciplinary learning
    - Workshops and trainings
    - Technical meetings between university project teams and ASAB mentors
    - Center meetings with poster sessions and social interactions
    - Stakeholder input on our technologies and agriculture testbeds

- Executing evidence-driven engagement and technology adoption processes via Project 34_ ENGAGEMENT, spanning the EWD, DCI, and IE functional components, led by UF Dept. Ag Education and Communication expert faculty
- Engaging with growers and stakeholders early in the technology development cycle
- Fostering outreach and knowledge sharing

YEAR 4 ACTIVITIES

Table 4G.1 details our milestones and assessment of progress at the end of Year 4. Additional details about our Year 4 activities are provided in the following sections.

Table 4G.1. Summary of Innovation Ecosystem milestones for Year 4.

	Activities	Proposed Year 4 Milestones	Assessment (as of August 2024)
Culture of Innovation	Education	2 student workshops / professional development events; Expand role of Entrepreneurial Mentors	Engaged 2 Entrepreneurship Mentors, who presented 2 workshops for students & others at Annual Meeting
	Entrepreneurship	1 I-Corps team + 1 Startup	1 new I-Corps team (+1 completed I-Corps) + 3 active startup endeavors
	IP Generation	10 invention disclosures / 15 patent applications (cumulative)	15 invention disclosures / 21 patent applications (cumulative)
Industry Partnerships	IP Licenses	1 licensed technology	No patent licenses, but multiple copyrighted software codes are published
	Internships/Externships	4 IPAB internships	2 IPAB internships (Deere and Corteva Agriscience)
	Permanent Hires	1 IPAB permanent hire	1 IPAB permanent hire (Corteva)
Stakeholder Engagement	Center Memberships	24 IPAB + 14 ASAB	21 IPAB + 19 ASAB members
	Visibility	2 marketing pieces + 1000 social media impressions + 2 conference booths	4 articles featuring IoT4Ag (2 in Sept 2023, 1 in June 2024, and 1 in July 2024), 5700 impressions on X/Twitter, 1894 views on YouTube, 3,280 post views on LinkedIn + 16 IoT4Ag exhibits/booths
	Stakeholder Interactions	6 stakeholder interactions	16 stakeholder interactions (conferences, fairs, booths, field days, etc.)

	Engagement Strategy	Establish a science-based approach to stakeholder engagement	Created a comprehensive, science-based approach to stakeholder engagement, including a formal social science project led by Katie Stofer (UF)
	Technology Adoption	Explore evidence-based approaches for stakeholder engagement to foster technology adoption	Established Adoption Readiness Levels (ARLs), inspired by Dept. of Energy

Culture of Innovation:

- In response to feedback we received at the Year 3 site visit, we held a center-wide seminar with representatives from all four core institution tech transfer offices in January 2024 to explain the university-specific processes for filing invention disclosures and prosecuting patent protection. By reducing knowledge barriers, this activity inspired a significant response from our center faculty and students.
- Received 7 new invention disclosures; filed 13 patent applications (center lifetime totals of 15 invention disclosures and 21 patent applications filed through end of Year 4); corresponding invention rate of $1.3M/disclosure.
- Infusion of Adoption Readiness Levels (ARLs) into project descriptions, assessment, and milestone charting.
- Leveraged our two external "Entrepreneurship Mentors"—York Eggleston and Andy Ziolkowski—to continue providing mentorship and training, notably a breakout session entitled "Entrepreneurship Start-Ups" at the June 2024 Annual Retreat.
- Presentation to ILO/SPI Working Group: "Stakeholder Engagement Case Studies", Aug. 30, 2024, recording and slides at https://erc-assoc.org/innovation-ecosystem-resources. (Steven Weiner, Katie Sofer).
- Training session for new Gen-4 ILO/SPI's: "The ILO SPI Role at an ERC" and responsibilities re: stakeholders, June 14, 2024 (Steven Weiner).
- Penn PhD students Chavez Lawrence and Akhila Mallavarapu completed NSF I-Corps program; Akhila Mallavarapu (Penn postdoc) is forming a startup around Project 1_LEAFSENSE and applying for NSF SBIR/STTR. Akhila was selected and participated in Innovators Ignite: A Penn & Yale Showcase for "aspiring and diverse academic entrepreneurs" who presented their technologies to industry experts.
- UF PhD student Dieter Steinhauser, UF faculty David Arnold, and IPAB member Darren Raj/Agribugs, started the I-Corps program in Sept. 2024. The team is also positioning for an NSF SBIR/STTR.
- Had 4 internal Perfect Pitch competitors pitch at our 2024 Annual Retreat, and our center winner, Merced PhD student Marcos Zuzuarregui, pitched at the 2024 Biennial ERC meeting in Arlington, VA. Marcos is developing "Siri for ag" – an intelligent interface enabling end-users (growers) to control Ag-Tech resources with conversational, natural

language commands. For example, a user could speak a natural language request for collecting more data in areas of concern, and the system would use a combination of LLM, goal planning, and IoT4Ag path-planning and navigation technology to dispatch a UAV or other autonomous vehicles with appropriate sensors/cameras to collect requisite data from the appropriate location. An invention disclosure has been submitted. Filing a patent application is under consideration, as is startup formation. This invention is from Project 10_PATH PLANNING.

- Penn Wharton undergraduate student Sabrina Zhang conducted a business case analysis for IoT4Ag sensor technology during her summer internship for IoTAg, supervised by Kevin Turner and Steven Weiner. Sabrina's work included market research, interviews with internal and external Ag-Tech experts and investors, and an ROI framework for validating value propositions for IoT4Ag technology.
- The SUBSURFACE_SENSE project topic was pitched by Penn faculty Kevin Turner and Troy Olsson and selected as one of two winning technologies for Penn's Y-prize competition. Three out of four Y-Prize student finalists were based on the IoT4Ag technology, and the winning team leveraged the technology for a medical/health application.
- We have begun discussion with IPAB about an industry-membership-funded initiative specifically to fund business development activities around IoT4Ag technologies (see **Appendix II**).

Industry Partnerships:

- Sustained our IPAB footprint nationwide and globally: added our first Medium size (500-2500 employees) company (Nordic Semiconductor), and a new Small and a new Very Small company.
- During Year 4, IoT4Ag had 21 organizations on the IPAB (see **Table 4G.2**): 5 Large, 1 Medium, 7 Small, 4 Very Small, and 3 Transition Partners.
- Held joint IPAB/ASAB meeting on July 25, 2024 to review our response to SWOT in preparation for the NSF Site Visit.
- Held joint IPAB/ASAB meeting on Jan. 11, 2024 to welcome new members, plan collectively for the upcoming Summer meeting at the Annual Retreat, review our cadence and processes for feedback on projects, brainstorm new board members to recruit, and provide a forum for general discussion.
- Held joint IPAB/ASAB lunch and dinner meetings at Annual Retreat in June 2024. IPAB members actively participated in the Annual Retreat, including as panelists during joint ops panel discussions. IPAB/ASAB members also participated in the student-led Boot Camp student-industry mixer.
- Held joint IPAB/ASAB on July 25, 2024 to review Annual Retreat feedback, discuss Adoption Readiness Levels, collect SWOT input, and elect IPEC members. Elected 9 IPEC representatives: Diganta Adhikari/Chair (Syngenta), Jordan Hesterman (FMC), Clay Hine (Nordic), Michael DeSa (AgSensor), Nathan Dorn (farm-ng), Darren Raj (AgriBugs), Marcel Zevenbergen (imec One Planet), and Ryan McKibben (Florida Dept. of Ag.).

- Assigned one or more IPAB and ASAB liaisons to 22 out of 24 Center projects.
- Engaged industry members in our sustainability planning, and brainstorming led to the development of the proposed IoT4Ag Innovation fund.

Table 4G.2. 21 IPAB member companies active in Year 4. *Italicized organizations* are those organizations whose membership ended in Year 4. **Organizations in bold** are new in Year 4. Organizations with ** signed agreement in Year 4 but membership payment received after August 31, 2024.

	Company/Organization Name	Sector
	IPAB Members	
1	AgriBugs	Industry
2	AgSensor Solutions	Industry
3	Aigen	Industry
4	*Augean Robotics, Inc. (Burro) (ended 11.30.2023)*	*Industry*
5	Bayer Crop Science	Industry
6	Ben Franklin Technology Partners	Other Sector
7	Corteva Agriscience (Pioneer Hi-Bred International)	Industry
8	Deere and Co.	Industry
9	**Farm-ng ** **	**Industry**
10	*FixPosition Ag (ended 3.31.2024)*	*Industry*
11	FMC Corp.	Industry
12	Headwall Photonics, Inc.	Industry
13	imec - OnePlanet Research	Other Sector
14	**MARVIL, Inc ****	**Industry**
15	**Nordic Semiconductor ****	**Industry**
16	*Pure Biomass (ended 3.31.2024)*	*Industry*
17	*SoilTech Wireless (ended 9.30.2023)*	*Industry*
18	SunSouth, LLC	Industry
19	Syngenta Group	Industry
20	*Trefos Inc (Treeswift) (ended 11.30.2023)*	*Industry*
21	Wabash Heartland Innovation Network	Other Sector

Stakeholder Engagement:

- Grew the Agricultural Systems Advisory Board (ASAB), adding 2 new members for a current total of 19 (see **Table 4G.3**). This board comprises non-fee-paying members from

producers, crop consultants, associations/consortia, and extension agents. These entities play a large role in the agriculture industry, and serve important, but different roles than typical ERC IPAB members.

- Since Feb. 2023, Katie Stofer (UF Dept. of Agricultural Education and Communications Dept.), Project 34_ENGAGEMENT has executed evidence-based methods to enhance our stakeholder engagement. Stofer led a panel at the 2024 Annual Retreat on stakeholder engagement with Maria Ridoutt-Orozco from the Community Alliance with Family Farmers, Rigo Rios (ASAB member) from the Latino Farmers Alliance, and Jim Ladlee (ASAB member) from Penn State Extension). In addition to engagements with other stakeholder constituencies, an IE-specific engagement with farmers and other Ag experts was deployed via an IoT4Ag booth at the San Joaquin Valley Small Farm Tech Expo, held at Madera Community College on March 1, 2024.
- Held joint IPAB/ASAB lunch and dinner meetings at the Annual Retreat in June 2024. ASAB members actively participated in our Annual Meeting as featured panelists and contributed to Year 4 SWOT Analysis.
- IoT4Ag student leaders host a student-industry mixer with ASAB partners to kick-off the student-led Boot Camp at the June 2024 Annual Meeting.
- The June 2024 Annual Meeting featured an extended visit to a large, multi-crop farm (both row crops and tree crops), Bowles Farming Company in the CA Central Valley, which included meetings and discussion with growers about challenges and opportunities for IoT, particularly in the highly regulated California Ag industry.

Table 4G.3. Summary of 19 ASAB member organizations in Year 4. **Organizations in bold** are new in Year 4. Individuals noted above are not listed in ERC Web as a "supporting organization".

	Company/Organization Name	Sector
	ASAB Members	
1	6 Gen Ag Services	Crop Consultant (Individual)
2	Almond Board of California	Consortium/Association
3	American Peanut Council	Consortium/Association
4	California Department of Food & Agriculture	State government
5	Cotton Incorporated	Consortium/Association
6	Davis Farm	Producer (Individual)
7	**Digital Divide Data**	**Consortium/Association**
8	Florida Dept of Agriculture and Consumer Services	State government
9	Indiana State Department of Agriculture	State government
10	Latino Farmers Alliance	Consortium/Association
11	Jim Ladlee (Penn State Extension)	Extension (Individual)
12	Pennsylvania Department of Agriculture	State government
13	RKE Terra Consulting (Tulane, CA)	Crop Consultant

14	SocioEnvironmental and Education Network (SEEN)	Consortium/Association
15	**Solutions from the Land**	**Consortium/Association**
16	Rodale Institute	Consortium/Association
17	UC Agricultural and Natural Resources	Extension
18	UF IFAS Southwest Florida Research and Education Center	Extension (Individual)
19	US Golf Association (USGA)	Consortium/Association

IPAB / ASAB Members: For this renewal request, **Figure 4G.4** shows the growth and sustainment of IPAB / ASAB memberships from Year 1 through Year 4. Additionally, **Figure 4G.5** illustrates the value chain for both IPAB and ASAB members. Lastly, **Figure 4G.6** shows the geographic distribution, both nationally and internationally, for the various organizations.

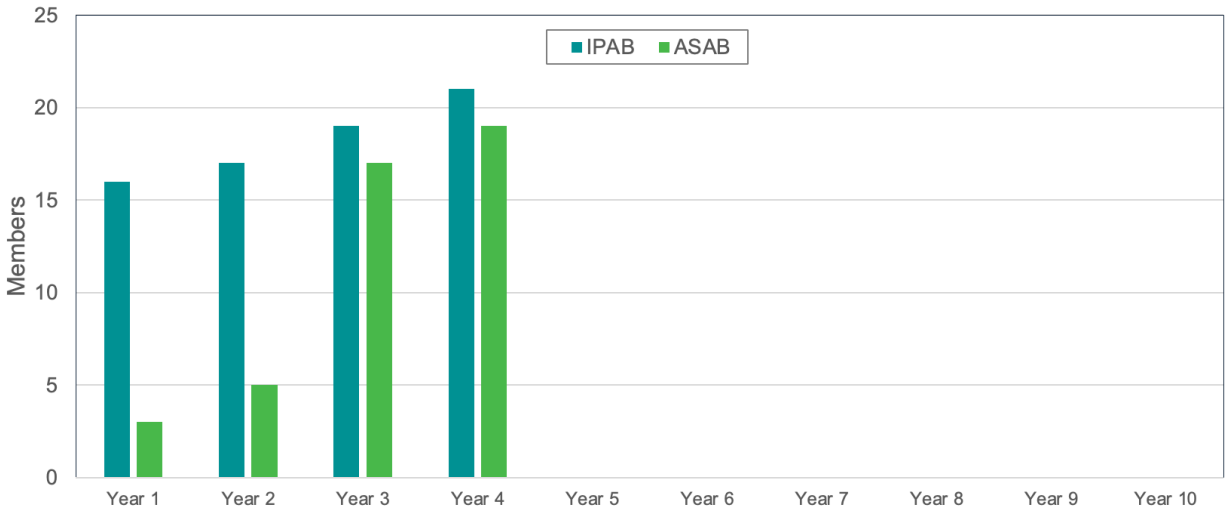


Figure 4G.4. Historical number of organizations active in the IPAB and ASAB by award year.

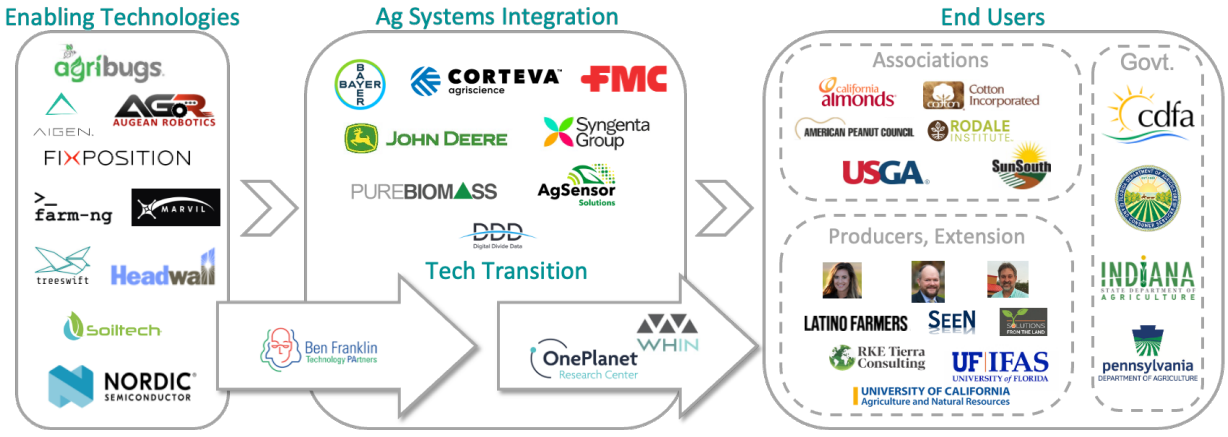


Figure 4G.5. Value Chain Chart including all IPAB and ASAB member organizations active during Year 4.

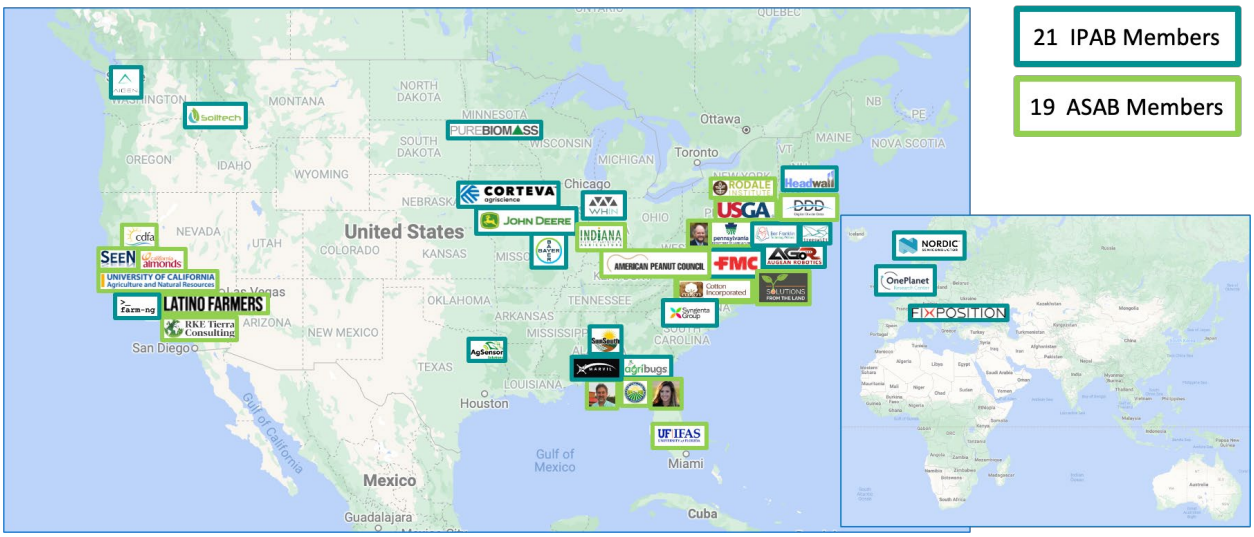


Figure 4G.6. Map of the geographic locations of all IPAB and ASAB member organizations active during Year 4.

Technology Transfer: In Year 4, center inventors reported 7 new invention disclosures and filed 13 new patent applications. This brings the center lifetime totals to 15 invention disclosures and 21 patent applications filed through end of Year 4, corresponding invention rate of $1.3M/disclosure. (See **Intellectual Property Table 18** and **Fig. 4G.7**).

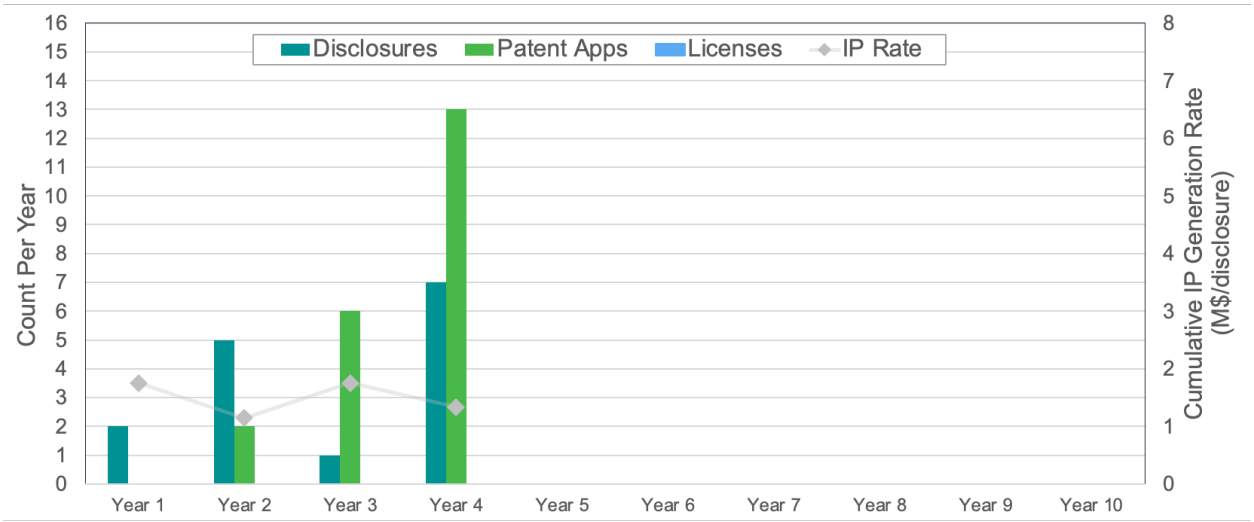


Figure 4G.7. Historical number of disclosures, patent applications, licenses by award year. Also shown is the cumulative IP generation rate (M$/disclosure).

Year 6-10 Innovation Ecosystem

Over the next five years, the IoT4Ag Innovation Ecosystem aims to advance Ag-Tech commercialization by fostering stronger partnerships between academia, industry, and agricultural professionals. Aspects of the plan include elements of technology, collaboration, professional development, and innovation. The goal is to launch new IoT-based precision agriculture technologies and support startup ventures by expanding the center's network of industry partners

and investors. Startups and an entrepreneurial spirit will continue to be cultivated within the center—we already have four different startup endeavors under pursuit. The ecosystem will enhance access to IoT4Ag's Ag-Tech User Facilities, providing companies with field-scale environments to test and refine their innovations. Additionally, the center will offer expanded mentorship and entrepreneurial training programs to students and researchers, helping bridge the gap between academic discoveries and market-ready technologies.

The Innovation Ecosystem will be closely linked with the three other foundational components of the center. It will work with the research teams to ensure that technological innovations align with stakeholder needs and industrial viability, streamlining their path to commercialization. Collaboration with the engineering workforce development programs will provide students and postdocs hands-on entrepreneurial experience, enhancing their career readiness. The ecosystem will also support stakeholder engagement by involving key industry players, farmers, and agricultural professionals in technology development and deployment. Furthermore, it will promote diversity and inclusion by ensuring broad participation in entrepreneurial activities, creating opportunities for underrepresented groups in Ag-Tech. This integrated approach will strengthen the impact of IoT4Ag's innovations, making them both commercially viable and widely accessible.

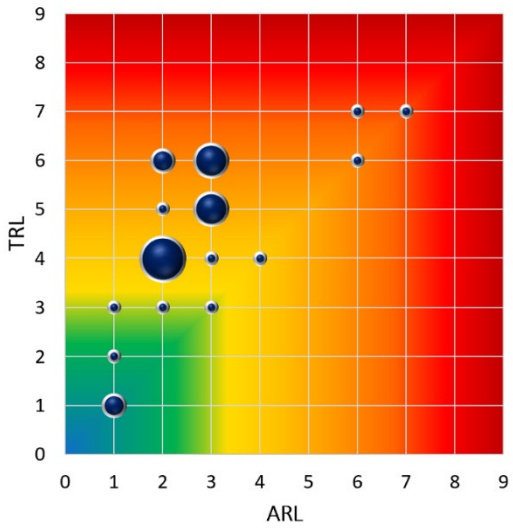


Figure 4G.8. Plot of technology readiness level (TRL) and adoption readiness level (ARL) for all active center projects. The size of the bubble represents the number of projects at that TRL/ARL (ranging here from 1 to 4).

Figure 4G.8 shows a summary of the TRL and Adoption Readiness Level (ARL) for all of our active center projects. The readiness level scales are defined in **Tables 4G.4,5**. Our goal is to continue increasing both TRL and ARL for individual technologies, while we also simultaneously integrate these technologies into larger engineering systems (what we call our "Joint Ops") and sustaining our inventive spirit to bring on new low TRL/ARL projects. Our most advanced projects are at TRL 7 (system prototype demonstration in an operational environment) and ARL 7 (technology used by multiple organizations that have no involvement with IoT4Ag) The systematic analysis and advancement of TRL and ARL is the focus of center Project 28_TECH_ADOPTION.

Table 4G.4 IoT4Ag Technology Readiness Level (TRL) Scale

Level 1	Basic principles of technology observed and reported
Level 2	Technology concept and/or application formulated
Level 3	Proof of concept / critical function demonstrated via experiments and/or modeling
Level 4	Validation and demonstration of technology in benchtop laboratory experiments
Level 5	Technology validation in IoT4Ag-related field or testbed

Level 6	Technology integrated into a system and validated in a testbed
Level 7	Full-scale, similar (prototypical) system demonstrated in a relevant environment
Level 8	Actual system completed and qualified through test and demonstration
Level 9	Actual system operated over the full range of expected conditions

Table 4G.5 IoT4Ag Adoption Readiness Level (ARL) Scale

Level 1	Conceived by the IoT4Ag project team
Level 2	Used by the IoT4Ag project team that conceived it
Level 3	Used by another IoT4Ag researcher (e.g., used in a testbed or another IoT4Ag project)
Level 4	Used by one organization involved with, but not funded by IoT4Ag (e.g., IPAB, ASAB member)
Level 5	Used by multiple organizations involved with, but not funded by IoT4Ag
Level 6	Used by one organization that has no involvement with IoT4Ag (e.g. another non-IoT4Ag university research team / company)
Level 7	Used by multiple organizations that have no involvement with IoT4Ag
Level 8	Used by one end-user who has nothing to do with IoT4Ag (e.g., farmer or producer)
Level 9	Used by multiple end-users who have nothing to do with IoT4Ag

RESPONSE TO SWOT

This section below responds to last year's NSF site visit SWOT pertaining to Innovation Ecosystem.

Weaknesses:

- There should be more description about the **interaction effectiveness** of Center researchers with the various advisory boards and councils. For example, how were the stakeholder

inputs used to inform the problems chosen and the strategies pursued? Very little is described about potential IP transfer and adoption of the proposed solution to/by the ASAB/IPAB members.

RESPONSE:

Center researchers engage with advisory board and council members through the Annual Retreat; Center-wide and student-led meetings, workshops, and activities spanning all four foundational components; and additionally in research, through project liaison and company-interest focused meetings, and student internships. Below we give examples where stakeholder input was used to inform problems chosen and strategies pursued:

1. Joint Op 3: Integrated Systems to Mitigate Disease and Pests. This Joint Op was established in response to feedback from SAB and ASAB members, representing different crop consortia.
2. Project 1_LEAFSENSE and Project 3_SUBSURFACE SENSE/Project 4_AIR BATTERIES, in response to IPAB member guidance, are designing sensors for disbursement with consideration of existing farm machinery and practices.
3. EWD/DCI: With guidance from DCI advisory board member Vilma Fuentes, we have worked with Santa Fe Community College, to hold outreach activities on their campus, to recruit REU program participants, and to include Santa Fe students at the 2023 Annual Retreat held on the UF Campus.

Regarding IP transfer and adoption, we have, for example, active participation with Corteva and Agribugs in center-funded projects. AgSensor Solutions has explored and negotiated with us regarding potential partnership in commercializing a portfolio of IoT4Ag technology, and they continue to watch closely for opportunities of interest. In addition, IoT4Ag Project 9_SEMANTIC MAPPING has resulted in significant new software (https://github.com/KumarRobotics/treescope), released as open source that has already been downloaded many times for use by the interested public, as well as publicly available dataset on trees (https://treescope.org/).

Additionally, the IPAB-proposed Innovation Fund currently under discussion includes several mechanisms for commercialization partnership.

- The Center Leadership needs to encourage more invention disclosures. Additional information should be provided to students and postdoc researchers about invention disclosure and patent filing processes. Many students were not aware of how IP protection works, and how to file disclosures. It seems that there is a lot of novel and protectable IP in the projects, and more awareness will help to increase the number of filings.

RESPONSE:

Thank you. We agreed with the SVT's recommendation of providing more information about invention disclosure and patent protection to students and postdocs. We have excellent resources – including among our Center faculty and staff as well as our local technology transfer offices – who provide responsive, helpful education on these topics.

In response to the SVT's recommendations, we doubled down on our informational/educational push to our Center students and faculty. In January 2024, we held a Center-wide meeting with a panel of representatives from all four core institution

tech transfer offices. The purpose was to explain the university-specific processes for filing invention disclosures and prosecuting patent protection. By reducing knowledge barriers, this activity inspired a significant response from our center faculty and students. We saw a dramatic jump in invention disclosures, receiving 7 new disclosures in Year 4, almost as many as received during Years 1-3 combined. We were also very pleased to see all four core institutions well represented in this year's disclosures.

- The developed partnerships for the innovation ecosystem are impressive and expansive, however it is not clear exactly how this will aid translation of projects. Technology to market considerations should be considered earlier and would be useful to do within the projects themselves.

RESPONSE:

Thank you for this observation and recommendation. In response to this feedback, we refined our TRL evaluation process since the last site visit. Specifically, we: (1) Had a center-level meeting focused on educating the IoT4Ag team about evaluating TRL scale in the context of IoT4Ag technologies (see **Table 4G.4** for TRL scale). (2) Established a process by which adoption readiness level (ARL) is also assessed for each project via an IoT4Ag specific scale (see **Table 4G.5** for ARL scale). (3) Developed a system to define/report the TRL of projects containing technologies with multiple TRLs. (4) Established a process in which TRL and ARL are explicitly reviewed in the annual project review cycle and corrected if needed. This included asking IPAB/ASAB and SAB reviewers, as well as the Executive Committee, if they agreed with the ARL/TRL assessment for each project.

In addition to project liaisons, technical poster sessions, field days, formal and informal student/faculty/industry/stakeholder interactions, and direct industry collaboration in multiple projects, we will continue to identify and facilitate more pathways for industry and stakeholder feedback into the project R&D and for projects to reach a maturity level appropriate for translation. As described above, The IPEC, executive leadership of our IPAB, proposed and is socializing amongst the members an IoT4Ag Innovation fund which includes supplemental funding to include business development activities, such as customer discovery.

In Year 4, we worked with a Wharton school student who performed a summer internship project in which she conducted a market study and developed a helpful template for evaluating potential ROI and market appeal of IoT4Ag sensor technologies.

We also continue to leverage our two Entrepreneurship Mentors, York Eggleston and Andy Ziolkowski, to help spin-out maturing technologies.

Middle-Band Requirements:

- The TRL system needs to be refined over the coming year, including developing a mechanism to train and educate the participants on invention processes and technology development assessments. Additional data should be tracked over the coming years, such as demographics of the contributors to the research project/invention disclosure, issued licenses, and generated revenue.

RESPONSE:

We appreciated the SVT feedback and, as described above, we reviewed/refined our TRL scale, defined and implemented an ARL scale, and held a Center-wide meeting to educate participants on the TRL/ARL project evaluation. We also held informational/educational push to our students and faculty with a panel from our tech transfer offices, and at the Annual Retreat, with our innovation mentors. We are very pleased to see all four core institutions well represented in this year's disclosures and 100% student participation in all Center disclosures.

- It would be useful to know what barriers exist for adoption of technology (e.g., cost metrics and social factors). Social economic considerations were mentioned but not elaborated about.

RESPONSE:

IoT4Ag is driven by the agricultural-specific use case of IoT technologies and systems, i.e., scale, environment, and socioeconomics.

IoT4Ag is working to take down **technological barriers**, by constraining technology and system definition, design, development, and deployment to meet the scale, environment, and cost of agricultural farming, e.g., by upfront specifications for materials, manufacturing processes, and device designs for sensors and their batteries to be low cost, biodegradable, and deployable using existing farming infrastructure and practices; by developing algorithms and building models to fuse spatially, temporally, and compositionally heterogeneous data inherent to the scale and environment of agriculture.

IoT4Ag is also working to remove **barriers to** technology and system **adoption**. For example:

- *Barrier - Cost of Technology and Systems*: IoT4Ag is creating technologies and systems to be affordable for agricultural farming, which has a distinctly different cost structure, use cycles (i.e. seasonal), and ramifications than IoT technologies for health, home, manufacturing, transportation etc.
- *Barrier - Deployment Consistent with Existing Farming Practices*: its is not just the cost of farming infrastructure, but IoT4Ag is working to create technologies consistent with current agricultural practices; by learning from IPAB, ASAB, and SAB members and farmers; and to engage community colleges, Ag organizations (e.g. 4-H, MANNRS), and agricultural professionals in workforce development activities/events to educate farmers on the use of IoT technologies and systems
- *Barrier - Trusted Relationships*: IoT4Ag is working to build trusted relationships and social networks with extension agents, crop consultants, early adopters/leaders etc through Ag Professional Engagement activities and with IPAB and ASAB members (e.g., Latino Farmers, SEEN) and regional organizations (e.g., PA Ag collaborative).

A major enhancement during Year 4 was the formalization of Project 34_ENGAGEMENT so specifically address stakeholder needs and barriers to adoption.

INPUTS & RESOURCES	ACTIVITIES	OUTPUTS	OUTCOMES		
			KNOWLEDGE SHORT-TERM	ACTION MEDIUM-TERM	IMPACTS LONG-TERM
•NSF funding and ERC program resources •Excellent faculty; undergraduate, graduate, and postdoctoral fellows; and staff •State-of-the-art PI research laboratories and shared experimental and cloud and edge computing facilities •Existing and innovative science and technologies •Agricultural extension campuses with row and tree crop control, plot, and field and orchard-scale instrumented testing facilities, representing the diversity of crops and agricultural environments in the US •Existing and new relationships with industry members, government and innovation partners, and the end-user community of growers joining our industry practitioner and Ag-systems advisory boards •I-Corps/IUCRC sites •University tech-transfer offices and incubators •Background IP	•Disseminate IoT4Ag programming *via* webpage and social media •Marketing IoT4Ag and lead generation •Execute core research program and sponsored research projects •Creation of intellectual property (patents, copyrights, datasets) •Research exchange and student – faculty – industry/government professional networking *via* IoT4Ag meetings, newsletters, workshops, short courses, and webinars •Industry and Ag-systems guided research project definition and field-scale deployments •Technology demonstrations at university testbeds and field days •Host industry members as visiting scientists at university partner sites •Student business plan development and senior design projects •Market research and competitive analysis	•Marketing pieces and campaigns •Impressions, new leads, and conversions •Meetings, newsletters, workshops - short courses - webinars •Research projects guided by market needs •>$3M memberships fees received •An engaged and vibrant IoT4Ag industry membership spanning the IoT for agriculture value chain and advancing/commercializing IoT4Ag tech •An engaged community of end-users in the Ag-systems advisory board •A robust culture of innovation and IoT4Ag inventions and startups •Patented and copyrighted technologies	•Knowledge of technology requirements through guidance from our stakeholders composed of industry members, government and innovation partners, and growers •Collaborative exchange on technology outlook, to benchmark current trajectories and new technologies in the lab and marketplace for precision agriculture •Educate members on intellectual property generation and how to and the importance of/avenues for technology transfer •Facilitate idea competitions (Perfect Pitch, Big Ideas, Y-Prize) and training (I-Corps)	•Benchmarking of IoT4Ag systems to current industry methods •Intellectual property disclosures, patent filings, and copyrights •Academia – government – industry partnership shortens the cycle to define-develop-deploy IoT4Ag systems •Technology transfer to industry *via* licensing of IoT4Ag IP •SBIR and investor backed start-up companies based on IoT4Ag technologies •IoT4Ag student fellows participate in internships and are hired upon graduation by industry members •Industry-driven sponsored projects •IoT4Ag builds on collaborations to receive externally funded joint university/industry awards (e.g., USDA, DARPA)	•IoT4Ag is recognized as a global leader in sense-communication-response systems for agriculture, and our technologies spur commercial innovation •IoT4Ag technologies are licensed by industry and its integrated systems are adopted by end users, transforming agricultural practices •Early IoT4Ag startup companies mature, and new ones are created •IoT4Ag partners in defining new standards for precision agriculture technologies and government policies and regulations •Increased profitability of industry members and growers •US is the global leader in precision agriculture •IoT4Ag technologies impact other business sectors

Figure. 4G.9 Innovation Ecosystem Logic Model

ERCWEB TABLE 14: NDUSTRIAL / PRACTITIONER MEMBERS, INNOVATION PARTNERS, FUNDERS OF SPONSORED PROJECTS, FUNDERS OF ASSOCIATED PROJECTS, AND CONTRIBUTING ORGANIZATIONS

Table: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects, and Contributing Organizations

Summary:
15 - Industrial/Practitioner Members
18 - Innovation Partners
0 - Funder of Sponsored Projects
0 - Funder of Associated Projects
0 - Contributing Organization

Section 1: 15 Industrial/Practitioner Members

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Member (Yes/No)	Total # of Sponsored Projects	Total # of Associated Projects
Industrial/Practitioner Members That Have Already Provided Current Award Year Support.									
AgriBugs, LLC	Industry	Engineering services	In-Kind Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	small (<500 employees)	no	0	0
AgSensor Solutions	Industry	Sensor systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participation in innovation/entrepreneurship activities Involvement in Technology Transfer	domestic	small (<500 employees)	no	0	0

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Member (Yes/No)	Total # of Sponsored Projects	Total # of Associated Projects
Aigen	Industry	AI-Generated Robotics for Agriculture	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board	domestic	small (<500 employees)	yes	0	0
Augean Robotics, Inc. (Burro)	Industry	autonomous robots for agriculture		Member of Center's Industrial Advisory Board	domestic	small (<500 employees)	no	0	0
Bayer Crop Science, LP	Industry	Sustainable agriculture	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	large (>1000 employees)	no	0	0
Corteva (Pioneer Hi-Bred International)	Industry	Information Technology	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	domestic	large (>1000 employees)	no	0	0
Fix Position Ag	Industry	Sensor systems	In-Kind Donations	Member of Center's Industrial Advisory Board	foreign	small (<500 employees)	no	0	0

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Member (Yes/No)	Total # of Sponsored Projects	Total # of Associated Projects
FMC Corp	Industry	Sustainable agriculture	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	large (>1000 employees)	no	0	0
Headwall Photonics, Inc.	Industry	Sensor systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	small (<500 employees)	no	0	0
Pure Biomass	Industry	Biomaterials		Member of Center's Industrial Advisory Board Involvement in Technology Transfer	domestic	small (<500 employees)	no	0	0
SoilTech Wireless	Industry	Sensor systems		Member of Center's Industrial Advisory Board	domestic	small (<500 employees)	no	0	0
SunSouth, LLC	Industry	agricultural and construction vehicles	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	small (<500 employees)	no	0	0

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Member (Yes/No)	Total # of Sponsored Projects	Total # of Associated Projects
Syngenta Crop Protection	Industry	Agriculture	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	foreign	large (>1000 employees)	no	0	0
Treeswift (Trefos), Inc.	Industry	Engineering services		Member of Center's Industrial Advisory Board	domestic	small (<500 employees)	no	0	0
Industrial/Practitioner Members That Will Provide Support by the End of the Current Award Year.									
Deere and Co.	Industry	agricultural and construction vehicles	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	domestic	large (>1000 employees)	no	0	0

Section 2: 18 Innovation Partners						
Organization	**Sector**	**Product Focus (Industry only)**	**Type of Involvement**	**Domestic / Foreign**	**Size (Industry Only)**	**New Partner (Yes/No)**
Almond Board of California	Other Sector	n/a	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	n/a	yes
American Peanut Council	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	yes
Ben Franklin Technology Partners Southeastern PA	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	no
California Department of Food & Agriculture	State government	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	no
Cotton Incorporated	Other Sector	n/a	Member of Center's Industrial Advisory Board Involvement in Technology Transfer	domestic	n/a	no
Digital Divide Data Ventures LLC	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	yes
Florida Dept of Agriculture and Consumer Services	State government	n/a	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	domestic	n/a	no

Organization	Sector	Product Focus (Industry only)	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)
Indiana State Department of Agriculture	State government	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	no
Latino Farm Alliance	Other Sector	n/a	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Participation in education/outreach activities	domestic	n/a	yes
Pennsylvania Department of Agriculture	State government	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	no
RKE Tierra Consulting	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	yes
Rodale Institute	Other Sector	n/a	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	n/a	yes
SocioEnvironmental and Education Network (SEEN)	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	yes
Solutions from the Land	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	yes

Organization	Sector	Product Focus (Industry only)	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)
Stichting IMEC Nederland - OnePlanet Research	Other Sector	n/a	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	foreign	n/a	no
UC Agriculture & Natural Resources	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	no
US Golf Association	Other Sector	n/a	Member of Center's Industrial Advisory Board	domestic	n/a	no
Wabash Heartland Innovation Network	Other Sector	n/a	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	domestic	n/a	no

Section 3: 0 Funder of Sponsored Projects

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)	Total # of Sponsored Projects
There are no organizations of the organization type Funder of Sponsored Projects for which support has been received.								

Section 4: 0 Funder of Associated Projects

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)	Total # of Associated Projects
There are no organizations of the organization type Funder of Associated Projects for which support has been received.								

Section 5: 0 Contributing Organization							
Organization	**Sector**	**Product Focus (Industry only)**	**Type of Financial Support**	**Type of Involvement**	**Domestic / Foreign**	**Size (Industry Only)**	**New Partner (Yes/No)**
There are no organizations of the organization type Contributing Organization for which support has been received.							

Section 6: Summary					
Sector	**Industrial/Practitioner Members**	**Percent Foreign**	**Percent Small**	**Percent Medium**	**Percent Large**
Industry	15	13%	67%	0%	33%
Total	**15**	**13%**	**N/A**	**N/A**	**N/A**

ERCWEB TABLE 15: ORGANIZATIONAL INVOLVEMENT IN INNOVATION AND ENTREPRENEURSHIP

Table: Organization Involvement in Innovation and Entrepreneurship Activities					
Organization Name	**Innovation/Entrepreneurship Training Activities**	**Provides Incubation Facilities**	**Technology Screening Activities**	**Connections to Sources of Commercialization Funding**	**Other Activity**
AgSensor Solutions					YR2 Perfect Pitch Competition Judging at IoT4Ag Annual Meeting

ERCWEB TABLE 16: INNOVATION ECOSYSTEM PARTNERS AND SUPPORT, BY YEAR

Table: Innovation Ecosystem Partners and Support, by Year				
	Sep 01, 2020 - Aug 31, 2021	**Sep 01, 2021 - Aug 31, 2022**	**Sep 01, 2022 - Aug 31, 2023**	**Sep 01, 2023 - Aug 31, 2024 [1]**
Industrial/Practitioner Members	11	15	14	15
Innovation Partners	7	10	11	18
Funders of Sponsored Projects	0	0	0	0
Funders of Associated Projects	0	0	0	0
Contributing Organizations	0	0	0	0
Total Participating Organizations	**18**	**25**	**25**	**33**
Number of Member-Sponsored Projects	0	0	0	0
Number of Non-Member-Sponsored Projects	0	0	0	0
Total Number of Sponsored Projects	**0**	**0**	**0**	**0**
Membership Fees Received - Cash	$59,750	$57,700	$163,500	$127,000
Membership Fees Expected from Prior Year Members [2]	N/A	N/A	N/A	$30,000
Member-Sponsored Projects Total Dollar Amount	$0	$0	$0	$0
Member-Associated Projects Total Dollar Amount	$0	$0	$0	$0
Member In-Kind Total Dollar Amount [3]	$18,841	$20,800	$1,500	$7,500
Total Dollar Amount, Industrial/Practitioner Member Support to Center	**$78,591**	**$78,500**	**$165,000**	**$164,500**

[1] Partial Award Year data only.

[2] Only applies for organizations that were already Industrial/Practitioner Members in a prior year.
[3] Data for this row is from the In-Kind Support reported in the Organizations section. There is no data prior to 2010 since it is a new field that year.

ERCWEB TABLE 17: TECHNOLOGY TRANSFER ACTIVITIES

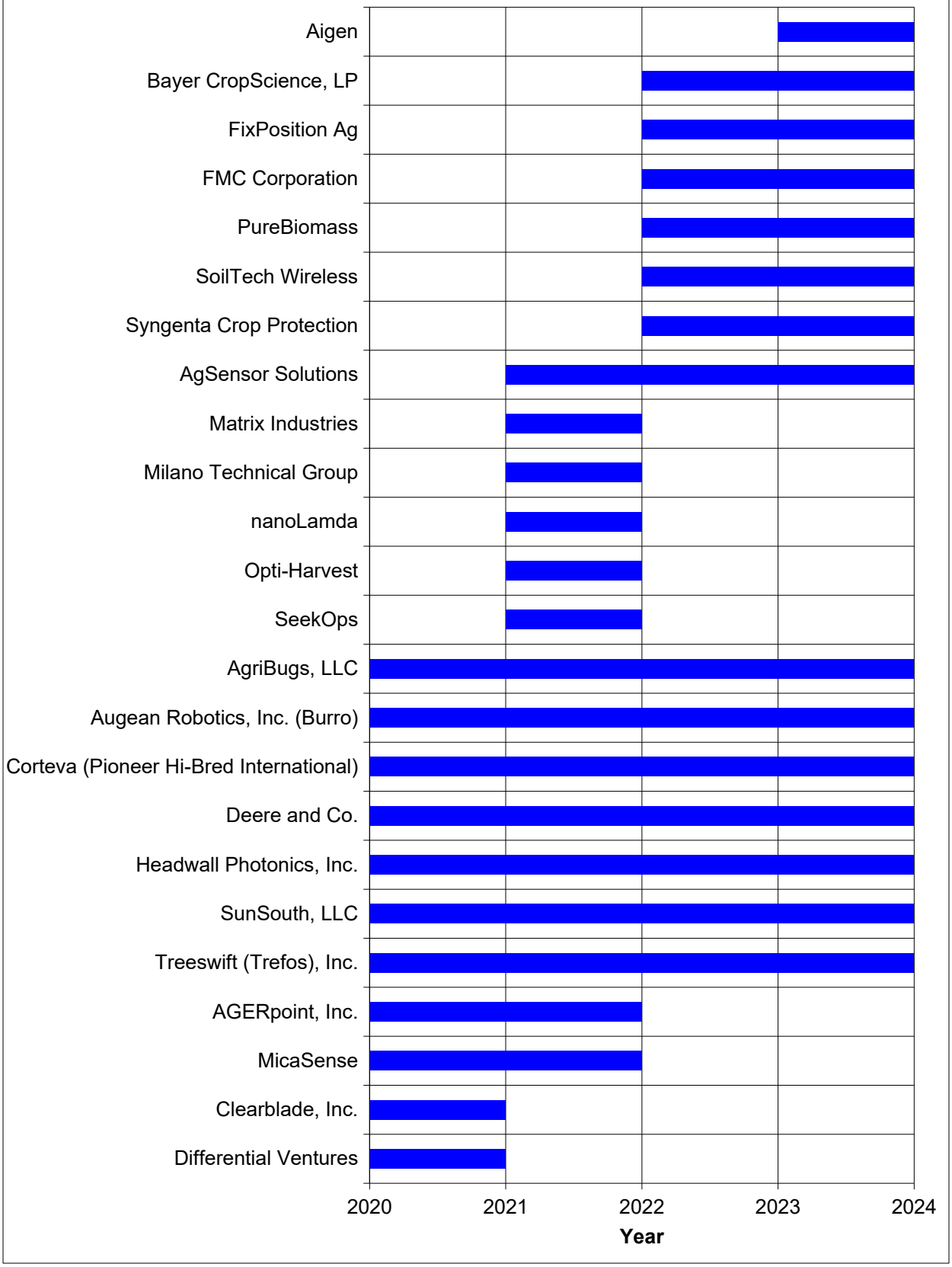
Table: Technology Transfer Activities									
Organization Name	Faculty On Site at Organization	Faculty Instruction to Organization	Individual from Organization on Lead Institution Campus	Licensed Software	Licensed Technology (other than software)	Graduate Hired by Organization	Student On Site at Organization	Participation in Test Bed	Other Activities
AgriBugs, LLC									
AgSensor Solutions		✔							
Aigen									
Almond Board of California									
American Peanut Council									
Augean Robotics, Inc. (Burro)									
Bayer CropScience, LP									
Ben Franklin Technology Partners Southeastern PA									
California Department of Food & Agriculture									
Corteva (Pioneer Hi-Bred International)	✔		✔						
Cotton Incorporated		✔							
Deere and Co.		✔							
Digital Divide Data Ventures LLC									
FixPosition Ag									
Florida Dept of Agriculture and Consumer Services		✔							
FMC Corporation									
Headwall Photonics, Inc.									
Indiana State Department of Agriculture									
Latino Farm Alliance									
Pennsylvania Department of Agriculture									
PureBiomass	✔						✔		
RKE Tierra Consulting									
Rodale Institute									

Organization Name	Faculty On Site at Organization	Faculty Instruction to Organization	Individual from Organization on Lead Institution Campus	Licensed Software	Licensed Technology (other than software)	Graduate Hired by Organization	Student On Site at Organization	Participation in Test Bed	Other Activities
SocioEnvironmental and Education Network (SEEN)									
SoilTech Wireless									
Solutions from the Land									
Stichting IMEC Nederland - OnePlanet Research									
SunSouth, LLC									
Syngenta Crop Protection									
Treeswift (Trefos), Inc.									
UC Agriculture & Natural Resources									
US Golf Association									
Wabash Heartland Innovation Network									

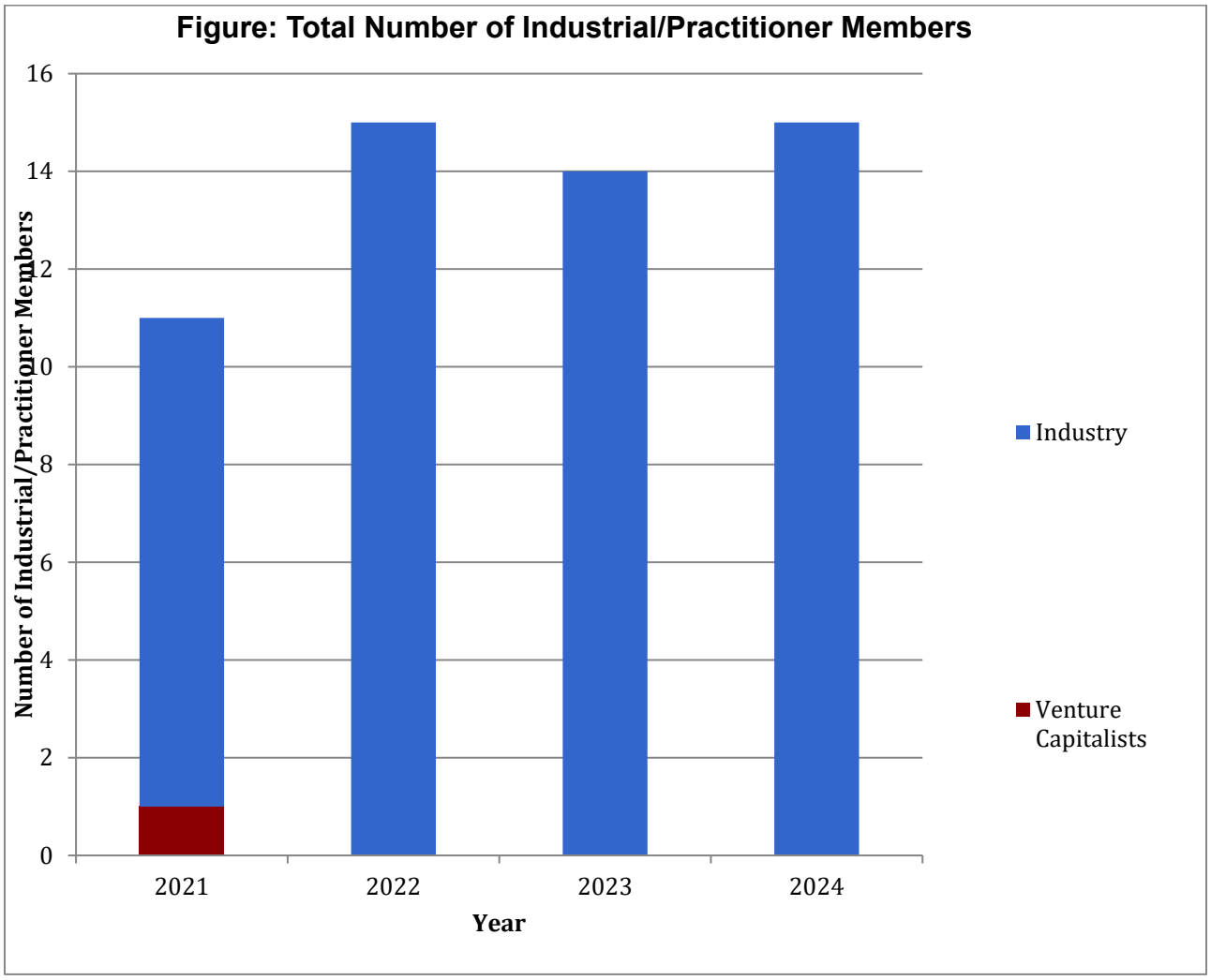
ERCWEB FIGURE 10: LIFETIME INDUSTRIAL / PRACTITIONER MEMBERSHIP HISTORY

See next page for the Lifetime Industrial / Practitioner Membership History figure.

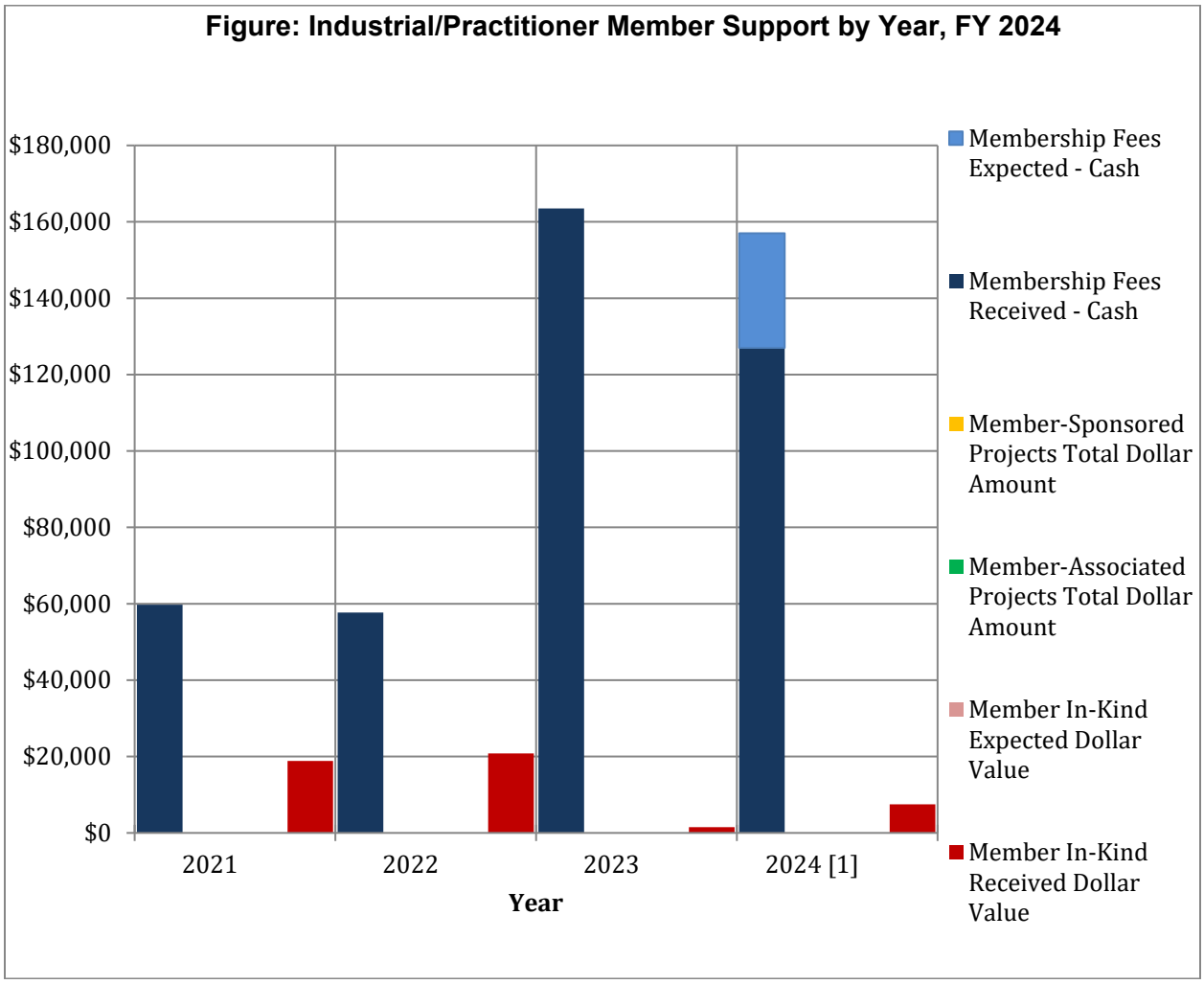
Figure: Lifetime Industrial/Practitioner Membership History



ERCWEB FIGURE 11: TOTAL NUMBER OF INDUSTRIAL / PRACTITIONER MEMBERS



ERCWEB FIGURE 12: INDUSTRIAL / PRACTITIONER MEMBER SUPPORT, BY YEAR



[1] - Member support provided through end of current reporting year (includes only partial data)

ERCWEB TABLE 18: INTELLECTUAL PROPERTY

Table: Intellectual Property					
IP License # or Name	**IP License Title or Name**	**IP Category**	**Brief Description of Technology**	**IP Owner**	**Year Awarded**
CAPP 69790	Automated Systems and Methods for Agricultural Crop Monitoring and Sampling	PP	Novel agricultural robot called the Purdue AgBot (P-AgBot), designed for autonomous navigation, crop monitoring, and crop sampling that can be applied in-row and under canopy. Proposed monitoring approaches have been designed to extract key morphological characteristics of crops.	Purdue University	2022
INV-210281	Hybrid Electromechanical Transformer	PP	Device uses coupled electromechanical transducers (one electrodynamic, one piezoelectric) to exchange electrical power between input & output ports, affording large voltage/current/impedance ratios (>100x) between the two ports, allowing power & signal coupling between different electronic circuits	University of Florida	2021
Invention ID: INV-240160	Wireless Power for Buried Electronics	PP	Wireless power transmission to power underground electronics mounted on moving infrastructure. When the transmitter passes over buried transmitter, power is delivered to buried system to enable deployment and energy sustainment of underground sensor networks	University of Florida	2023
Invention ID: INV-240169	SpectralZoom: An Adaptive Resolution Hyperspectral Camera	PP	Novel camera design and a vision transformer-based (ViT) algorithm that alleviate both the captured data footprint and the computational load for hyperspectral segmentation.	University of Florida	2023
Invention ID: INV-240143	Agricultural Drone Port	PP	Autonomous drone port is a collaborative research project with Agribugs and IoT4Ag. Purpose is to design and build a system that serves as an autonomous drone port for deployment in agricultural environments. Goal is a fully autonomous station requiring minimal human intervention.	University of Florida / Agribugs	2023
P-AgBot: In-Row & Under-Canopy Agricultural Robot for Monitoring and Physical Sampling	P-AgBot: In-Row & Under-Canopy Agricultural Robot for Monitoring and Physical Sampling	C	This repository contains a code for crop monitoring modules (corn height, corn stalk radius) for ROS compatible UGVs: https://github.com/kimkt0408/P-AgBot	Purdue University	2024

IP License # or Name	IP License Title or Name	IP Category	Brief Description of Technology	IP Owner	Year Awarded
P-AgSLAM: In-Row and Under-Canopy SLAM for Agricultural Monitoring in Cornfields	P-AgSLAM: In-Row and Under-Canopy SLAM for Agricultural Monitoring in Cornfields	C	Purdue AgSLAM or P-AgSLAM is an in-row and under-canopy Simultaneous Localization and Mapping (SLAM) framework which is designed for robot pose estimation and agricultural monitoring in cornfields: https://github.com/kimkt0408/pagslam	Purdue University	2024
PENN 23 - 13095	Smooth and Biodegradable Nano-cellulose Composites for Printed Electronics	FP	Novel cellulose-based composite paper, which has high surface smoothness and low porosity, as well as a process for its fabrication. This composite consists of a standard paper substrate that is coated with a thin layer of TEMPO-oxidized cellulose nanofibril (CNF) solution.	University of Pennsylvania	2023
PENN 23-10197	Nanoparticle ink based patterning of inorganic materials	FP	Single-step direct nanocrystal ink-based imprint process for fabricating TiO2 oxide-based dielectric metasurfaces using nanocrystal inks on rigid and flexible polymeric substrates, paving the way for high volume and low-cost manufacturing of inorganic nanostructures.	University of Pennsylvania	2022
Penn 23-1042	Biodegradable Batteries Operational in the Air and Soil	FP	Zn-air batteries built from biodegradable materials that can operate on or under the soil.	University of Pennsylvania	2023
Penn 23-10488	Environmental Sensors with Optical Metasurfaces	FP	Low-cost, biodegradable, passive leaf environmental sensors that can be easily deployed and measured using existing farm infrastructure and ground and aerial robots.	University of Pennsylvania	2023
Penn/PCI: 22-9924	Methods of forming colloidal copper nanoparticle-based, air-stable, conductive, multiscale features	FP	We develop a colloidal Cu nanoparticle(NP) ink and room-temperature chemical treatments to achieve highly conductive and air-stable thin films. We also demonstrate the integration of such Cu NP ink and chemical treatments with solution-based fabrication processes to construct device structures.	University of Pennsylvania	2022
Penn/PCI: 24-10813	Project_4 Air Batteries: Biodegradable Zn-air Battery for Active Sensing	PP	Improved Zn-air batteries built from biodegradable materials that can operate on or under the soil	University of Pennsylvania	2024

IP License # or Name	IP License Title or Name	IP Category	Brief Description of Technology	IP Owner	Year Awarded
Purdue ACRE Cornfield Dataset	Purdue ACRE Cornfield Dataset	C	This dataset, collected with Purdue-AgBot (P-AgBot) at the Agronomy Center for Research and Education (ACRE) during Summer 2023, supports research in autonomous navigation and crop monitoring in cornfields: https://github.com/kimkt0408/ACRE-Dataset	Purdue University	2024
Treescope	TreeScope: An Agricultural Robotics Dataset for LiDAR-Based Mapping of Trees in Forests and Orchards	C	Treescope is an interactive HTML pretty-printer and N-dimensional array ("tensor") visualizer, designed for machine learning and neural networks research in IPython notebooks. It's a drop-in replacement for the standard IPython/Colab renderer: https://github.com/google-deepmind/treescope	University of Pennsylvania	2024
UC Case Number:2024-916	A Portable Sensor for Plant Water Stress Detection and Irrigation Scheduling	PP	Sensor system predicts plant water status for efficient irrigation scheduling. Both row crops and tree crop growers and crop consultants can use this cost-effective sensor for detecting water stress and efficient irrigation scheduling.	University of California - Merced	2024
UF T19194	Bulk Depolymerization of Polymethyl Methacrylate Copolymers Via Pendent Group Initiation	PP	A method of chemically recycling vinyl polymers by initiating depolymerization via thermally or photochemically labile pendent groups. This approach could prove useful in the recycling of molecularly-imprinted polymer systems designed for the detection of analytes in the field.	University of Florida	2024
UF T19241	Polymers and Methods of Depolymerization of Polymers Using Chain-End Initiation	PP	A method of chemically recycling vinyl polymers by initiating depolymerization via thermally or photochemically labile end groups. This approach could prove useful in the recycling of molecularly-imprinted polymer systems designed for the detection of analytes in the field.	University of Florida	2024

ERCWEB TABLE 19: TECHNOLOGY TRANSFER

Table: Technology Transfer				
Adopting Company	Technology	Industrial Application		Impact
		When Transferred	Use in Company	
No technology transfer records have been entered.				

ERCWEB TABLE 20: START-UP FIRMS

Table: Start-Up Firms						
Name of Firm	Contact Information	Date Established	Principal Name/Relationship	Funding Status	Technology	Market Impact or Societal Benefit
No start-up firms have been entered.						

4H. EVALUATION AND ASSSESSMENT

EVALUATION PURPOSE AND AUDIENCE

Evaluation is an integral component of the IoT4Ag ERC and is conducted on both a formative and summative basis. The external evaluation team, located at Arizona State University, aims to provide credible and usable information to the IoT4Ag ERC's leadership, managers, and all other relevant interest holders while also assessing the project's logic and theory, implementation, effectiveness, outcomes impact, and sustainability. This year the evaluation team spent time developing professional relationships with new Center leaders/staff, hiring/recruiting evaluation team members, developing protocols, increasing our understanding of the Center, and evaluating Center signature programming.

EVALUATION APPROACH

The evaluation team utilized a Values-Engaged, Educative (VEE) approach (Boyce, 2017; Boyce & Rivera, 2023; Greene, DeStefano, Burgon & Hall, 2006; Greene et al., 2011; Reid, 2020). The National Science Foundation provided funds for the development and field testing of the VEE approach in acknowledgment of the fact that past evaluations of STEM programs have generally neglected to take into account culture, diversity, and inclusion. According to the VEE method, effective integration of cutting-edge scientific material, excellent instructional pedagogy, and sensitivity to diversity and equity problems are the hallmarks of high-quality STEM programming. STEM educational programs have the potential to embody some of the essential qualities outlined by the VEE approach but may fall short in other areas. For instance, a program may prioritize the recruitment and mentorship of underrepresented groups, but neglect to provide them with the necessary tools and training required for meaningful participation. Alternatively, a program may offer outstanding labs and resources with exceptional instruction but fail to include historically underrepresented groups, resulting in the homogeneity of STEM and potentially limiting its scientific contributions (Greene, DeStefano, Burgon & Hall, 2006). The VEE approach strives to involve all relevant stakeholders, including those who are typically marginalized, in the evaluation process. Its goal is to provide insight to those invested in an organization's programs. In short, the VEE approach focuses on context-based evaluation that incorporates science, diversity, and education.

EVALUATION ACTIVITIES

IRB approval

The evaluation team took the necessary steps to obtain and maintain approval from the Arizona State University Institutional Review Board (IRB). This measure was taken to ensure that all ethical and legal guidelines are adhered to and that the rights, and well-being of all participants were fully protected.

Pathway to Ph.D. Program (PPP)

As in previous years, a virtual Pathway to Ph.D. (PPP) program was held on September 9, 2023, targeting motivated undergraduate and master's students with aspirations for graduate school. The PPP program targets third and fourth year undergraduate and master’s students who are currently majoring in engineering, agricultural science, or a related discipline, have an interest in IoT

technologies in agricultural settings, and are interested in pursuing a PhD program.

The workshop aimed to guide these students through the graduate school and fellowship application processes and provided mentorship from faculty and graduate students affiliated with NSF-ERC, including several current and former NSF Fellows. After the program, both participants and graduate student mentors were invited to complete post-workshop surveys via Qualtrics, which were conducted between October 17 and October 30. The surveys were completed by 21 mentors and 16 mentees. The IoT4Ag 2023 PPP report was subsequently submitted to the relevant interest holders within the Center.

Annual Meeting

The 2024 Annual Retreat spanned four days and featured approximately 22 sessions, including student activities, site or field visits, panel discussions, presentations, breakout sessions, and networking opportunities. Two members of the external evaluation team attended the retreat as participating observers, actively engaging in as many sessions as possible and presenting evaluation findings from the past year. Attendees were given up to a week to complete the post-meeting survey. By the time the survey closed, a total of 79 individuals had responded, accounting for about 70% of the registered participants for this year's retreat. A report was drafted and submitted to relevant interest holders of the Center to provide feedback, considerations, and recommendations based on observations, conversations with graduate students, and survey results from the 2024 IoT4Ag Annual Meeting. The IoT4Ag 2024 annual retreat report has been submitted to Center leaders.

REU

The IoT4Ag REU program aims to offer undergraduate students the chance to engage in research projects alongside an ERC faculty member and other researchers during the summer. The REU evaluation focuses on assessing students' experiences throughout the program, with particular attention to their professional growth, skill development, and interactions with faculty advisors, graduate student mentors, and fellow REU participants. The report also includes insights and experiences from the graduate student mentors regarding the REU program. The external evaluation team has completed and submitted the IoT4Ag 2023 REU report to Center leaders in Fall 2023. Data (focus groups and surveys) is currently being collected for the 2024 program and a report will be completed this Fall.

RET

Similar to the REU, the IoT4Ag ERC's RET program aims to offer Philadelphia-based K-12 STEM teachers the opportunity to collaborate with University of Pennsylvania scientists on innovative research aimed at addressing the societal grand challenge of food, energy, and water security by advancing technologies that enhance crop production. The external evaluation team collected feedback on the participants' experiences during the 2023 RET program through surveys (pre, mid, and post) and focus groups. The 2023 report was submitted in Fall 2023. Data is still being collected for the 2024 evaluation report. The data sources include pre-program focus groups, post-program focus groups, a check-in survey, and a post-program (exit) survey a report will be completed this Fall.

Building MSI/HBCU Scholars Network

The IoT4Ag center launched a pilot program aimed at increasing opportunities for underrepresented minorities to engage with large engineering research centers like IoT4Ag. The

initiative sought to involve faculty and students from Minority-Serving Institutions (MSIs) and Historically Black Colleges and Universities (HBCUs). The pilot program featured two faculty members and one undergraduate student from two different institutions. Participants spent approximately a month at the University of Pennsylvania, where they collaborated and networked with scholars, students, and labs at the institution. The external evaluation team conducted pre- and post-program interviews with participants to assess their expectations, experiences, and overall satisfaction with the program.

Evaluation Presentations Related to IoT4Ag ERC

The external evaluation team has also prepared and presented information related to evaluation methodology at conferences and invited speaker series. The team has presented at the American Evaluation Association conference in the past year and has also been accepted to present at the upcoming conference this October. Please see the citations below for past presentations related to the project.

Boyce, A. S., Tewari, N., Stone, C., Kwarase, P. K., & Ibrahim, M. (2024, February). *Positioning Evaluation to Challenge the Status Quo: The STEM Program Evaluation Lab.* University of Illinois at Chicago Educational Psychology Department Speaker Series.

Stone, C., Albrechtsen, C., Ibrahim, M., & Boyce, A. S. (2023). *Whose Stories Get Told? Toward Validation in Culture and Climate Studies*. Poster presented at the meeting of the American Evaluation Association, Indianapolis, IN.

KEY EVALUATION FINDINGS

PPP (report completed in December 2023)

Findings

- *Participants largely considered the PPP workshop activities as very useful.* The PPP participants found the workshop activities helpful, with the "Interactions with mentors" rated most useful by 100% of participants. The sessions on writing personal statements and reviewing research statements were also highly rated.
- *Mentees were generally satisfied with their PPP experience.* All respondents agreed or strongly agreed that they had a positive experience with the PPP program, except for one participant who had a neutral view on organization, indicating the program's overall success in meeting expectations.
- *Concerns with the mentorship experience and the limited variety of funding and fellowship opportunities exist.* Some participants were dissatisfied with their mentorship experience due to limited interactions, mentor-mentee mismatches based on field of study and research interests, and a shortage of mentors, resulting in mentors having multiple mentees.

Recommendations

- *Continue to provide PPP workshop experience for motivated undergraduate students.* Continue offering the PPP workshop, as all mentee respondents found the activities beneficial and were satisfied with their overall experience.
- *Improve the mentorship experience between participants and their respective graduate student mentors.* Participants and mentors expressed concerns about mentor-mentee interactions. To improve future workshops, program facilitators can better align mentor-

mentee interests and recruit additional mentors for a more successful experience.

- *Improve program satisfaction of future participants by presenting them with multiple graduate school funding and fellowship possibilities.* Organizers should consider expanding the range of funding and fellowship opportunities for PPP participants, as some expressed interest in a greater variety of options.

Annual Retreat (report completed in August 2024)

Findings

- Overall, the meeting was generally considered well organized and successful.
- The annual retreat largely met attendees' expectations, with most participants reporting satisfaction with presentations and activities. The poster session was the highest rated session.
- The meeting's meals and refreshments were generally perceived to be adequate. However, some of the attendees were unsatisfied with the breakfast provided.
- The schedule did not provide an adequate amount of time for rest and breaks between the different sessions or activities.

Recommendations

- *Provide breaks between sessions.* Attendee feedback and evaluation team observations highlighted a lack of breaks between sessions during the annual retreat. Additional breaks are needed throughout the day. This change will help reduce the risk of participant fatigue, which can lead to diminished concentration and lower morale. Introducing breaks will likely enhance overall efficiency and productivity in the meetings.
- *Continue providing and enhancing the poster session of the annual retreat.* Since the poster session was the most popular activity at this year's annual meeting, the Center should continue offering this opportunity to students. Further, a more interactive session could continue to foster networking among students, faculty, and other relevant participants.

2023 REU (report completed in September 2023)

Findings

- Participants' Expectations and Satisfaction
    - Participants were generally expected to gain research-related skills and competencies while gaining clarity about their academic and career goals in STEM. However, additional clarity around the expectations of participants is warranted.
    - A significant number of the participants did not express contentment with the "Clarity of expectations" in the program.

- Participants' Interactions with Graduate Student Mentors, Faculty and Peers
    - All the REU Participants expressed some level of satisfaction with their Interactions and Communications with their Graduate Student Mentors
    - The REU students were largely satisfied with their interactions with their faculty mentors.
    - The participants' experience with faculty mentorship fell marginally short of their expectations.
    - The participants had mixed reactions concerning their interactions with their peers.

- Professional Development
    - The REU program proved to be a valuable opportunity for participants to enhance their research skills and boost their self-assurance levels.
    - The REU program culminated in a noticeable upswing in the participants' science identity.

- Mentor and Facilitator Satisfaction
    - Mentors were generally satisfied with their mentees.
    - Participants had largely positive experiences with the stipend and housing arrangements but were less satisfied with the program orientation.
    - A minority of the REU mentors expressed satisfaction with the structure, organization, and communication of program expectations.

Recommendations

- Improve the program orientation to help REU students better understand the goals of the program and what is expected of them.
- Make professional developments more engaging and interactive to increase the prospects of REU participants socializing and networking with peers within and across sites.
- Continue providing authentic research prospects to the REU participants to amplify their scientific competence.
- Streamline the organizational structure of the program to improve communication from facilitators to other relevant people of stake in the program.

2023 RET (report completed in October 2023)

Finding

- Participants were satisfied with the vast majority of the RET program components. Satisfaction with the laboratory experience and clarity of program expectations varied slightly.
- Open-ended comments revealed that participants were highly satisfied with interactions with graduate student mentors. As is typically the case with summer experiences, participants were much less satisfied with their time with faculty advisors.
- Participants' skills increased as a result of the RET.
- Participants were highly satisfied with the curriculum design aspect of the RET program.

Recommendations

- *Continue to provide research and curriculum design experience for RET teachers under faculty and graduate student mentorship.* While the RET teachers felt they had relatively limited contact with their faculty mentors, they reported being highly satisfied with the research experience and their relationship and interaction with their graduate student mentors. Overall, this will facilitate the program to continue to deliver a well-rounded experience to RET teachers, enabling them to develop new skills and knowledge.
- *Provide more clarity regarding the time RET teachers are expected to spend in the laboratory and faculty/PI mentorship during program orientation.* Participants provided varied responses concerning their satisfaction with their time in the laboratory. To improve the lab experience, providing more clarity about how much time participants are expected to spend in the lab would be beneficial. Moreover, participants reported relatively less

satisfaction with the mentorship of faculty/PI due to the limited in-person interaction. Therefore, it would be helpful to clarify the number of interactions RET teachers are expected to have with faculty throughout the program to enhance their satisfaction.

FORTHCOMING EVALUATION REPORTS

2024 REU (anticipated to be completed Fall 2024)

- Data analysis in progress

2024 RET (anticipated to be completed in Fall 2024)

- Data analysis in progress

Building MSI/HBCU Scholars Network (anticipated to be completed in Fall 2024)

- Data analysis in progress

Comprehensive report (anticipated to be completed in late Fall 2024)

- Data analysis in progress

4I. RESOURCES AND INSITUTIONAL COMMITMENT

FACILITIES AND INFRASTRUCTURE

All faculty labs and university user and extension facilities are in place and being used by IoT4Ag personnel to carry out the Center's collaborative research agenda. The IoT4Ag headquarters are temporarily at Hayden Hall (240 S. 33rd Street, Philadelphia) on the main campus for YR4. The main office will soon be moved to new, permanent space in the main Engineering Complex, just around the corner from Hayden Hall. Headquarters is equipped for remote communication between universities and workforce development, diversity & culture of inclusion, and industry, government, and innovation partners, and broadly for external activities.

UC Merced constructed a unique infrastructure to implement the concept of IoT in a commercial orchard (*17_ORCHARD*). This infrastructure provides a significant amount of real-time plant and environment data from the site for scientists to develop and test different data analysis techniques and evaluate the performance of different sensors and sensor platforms. It provides an educational environment for the personnel involved in the projects, including postdocs, undergraduates, and graduate students to learn and develop new innovative IoT concepts for orchards. It is also a site used for showcasing to growers and the public on how a model IoT4Ag orchard will look like and operate. Purdue University uses Building 44 at the Agronomy Center for Research and Education (ACRE) to support field research by IoT4Ag researchers at Purdue. It was renovated in 2021 to support the needs of the Center and was the primary location for the first in-person IoT4Ag Annual Meeting in June 2022. IoT4Ag will open a new space at Penn in the new Vagelos Laboratory for Energy Science and Technology. The space will be used for IoT4Ag sensor fabrication and characterization.

The testbeds are located at Purdue University's Agronomy Center for Research and Education, at the University of California Merced's new Smart Farm, at the University of Florida's North Florida Research and Education Center, and at regional sites in California, Florida, Indiana, and Pennsylvania. These testbeds are being used to assess and demonstrate IoT4Ag solutions in the different agricultural environments of orchards and row crops, many of which are mainstays of the food supply chain, and in the different regional environments and cropping systems. IoT4Ag technologies are being deployed in phases from control facilities to plot and field scale university testbeds and in facilities and fields of our industry and agricultural partners. The testbeds serve as the sites for IoT4Ag technologies to come together in the Center's Joint Ops.

Infrastructure also includes physical sensors, apps, and software that communicate data, the communication technologies that move the bits (LoRa, WIFI, cellular, etc.), and storage media (cloud, local). Some of that infrastructure is local to a farm or business, but much of it requires an infrastructure system country wide. The infrastructure for agriculture also involves many different business and agency entities, so compatibility and interoperability are critical. IoT4Ag has research projects working toward developing a dramatically different-than-usual data management plan that enables data integration across siloed platforms, including what is generally considered private data with public data. For this sort of system to be widely adopted requires working demonstrations in a research environment that is reasonably "production-like". This is one of the key challenges that links the three thrusts of IoT4Ag.

COMMUNICATIONS

Remote communication capabilities are all in place and are heavily used to carry out collaborative research, workforce development, diversity & culture of inclusion, and innovation ecosystem activities. We utilize a Slack workspace for all IoT4Ag members, with channels for research groups, thrusts, sites, and more. The Slack workspace is actively used, averaging about 63 active members per month in YR4, with 183 total members who have used the IoTAg workspace at least once this past year.

Communication across all four partner institutions has primarily been conducted via Zoom meetings, including monthly center-wide presentations and trainings and monthly collaborative Thrust meetings. Google Drive is primarily used to file and make available documents and presentations relevant to IoT4Ag members. Center-wide recordings and presentation slides are also made available to members and, if relevant, the public through the IoT4Ag YouTube channel. For more frequent communication, Slack is used for all members to communicate with each other more easily, with channels for specific research or administrative topic areas. The IoT4Ag website also includes access to the member only webpage for students, postdoctoral fellows, faculty, staff, and advisory board members. This members' webpage is also used to share materials with the advisory board members, such as their charters, research project summaries and quad charts, and the Annual Retreat presentation slides, student posters, and recordings of that meeting.

In addition, the Administrative Director maintains an online reporting database to capture the data metrics needed for the annual report. The database mirrors the NSF ERCWeb site and enhances the accuracy and ease of data reporting. Each member (faculty, postdoctoral fellows, students, and staff) has a profile to report demographics, roles, project involvement, mentorship, and event attendance. Output and impact records capture publications, outreach and education events, mentorship, degrees earned, and jobs obtained for students, intellectual property, and personnel exchanges. Other records include ones for each research project and for the industry / practitioner companies. The database has also been used to produce reports to convert to AirTable databases of personnel, projects, and Center outputs to share with the leadership team and faculty for their review and to facilitate greater transparency and accessibility across the Center.

TENURE

IoT4Ag hierarchical mentoring is not just for students but supports junior faculty through tenure and promotion. The Center encourages and supports more junior faculty members by asking a more senior faculty member from the junior faculty member's home institution as well as a more senior faculty member who is disciplinarily closer to the junior faculty member to serve as mentors, providing both assistance to the junior faculty member in navigating and providing insight on the institutional specific evaluation process and in broadening their presence in their research community. In some cases, the senior faculty member can play both roles. This approach to mentorship will be used as new, junior faculty members join the Center.

LABORATORY SAFETY TRAINING AND PROCEDURES

All Penn students working in research labs where hazardous materials or equipment are used receive introductory and annual refresher lab safety training provided by Penn's office of Environmental Health & Radiation Safety (EHRS). These EHRS training modules cover such topics as general lab safety practices, personal protective equipment, risk assessment, hazardous chemical identification, hazardous waste, physical lab hazards, and emergency procedures.

Additional training is offered as needed for topics such as biological safety, lasers, radiation safety, and shipping of hazardous materials. The EHRS lab safety training is supplemented by in-lab, task- specific training provided by the research advisor or an experienced senior lab member. Research faculty are also required to update their lab's hazard list online annually or whenever hazards change. When this list is certified by the faculty member, all lab members receive an email with links to the sections of Penn's Chemical Hygiene Plan that apply to their lab's hazards. Additionally, EHRS conducts regular laboratory inspections to provide ongoing compliance assistance and education on lab safety.

The partner institutions follow the same process regarding laboratory safety training and procedures. Purdue University's Radiological and Environmental Management (REM) provides introductory and annual refresher lab safety training for all students working in research labs. REM also creates a strategic plan for safety at Purdue that provides a structure to communicate environmental, health, and safety issues across the institution.

University of Florida's College of Engineering Safety office created the "Lab Safety Kick-Starter" tool to share information, provide best practices, and identify training needs specific to each lab. Each person working in research labs must agree to attend all required trainings and comply with all requirements and guidelines, signing "Engineering Laboratory Safety Guidelines" form to confirm such.

University of California, Merced's Office of Environmental Health and Safety provides training to all students, faculty, and staff working in research labs. Courses are offered on a regular rotating or seasonal basis, depending on the specialized needs of each department, and this office along with the Office of Research jointly hold campus-wide lab safety days each year. This office also institutionalized a policy for lab safety training that identifies minimum training requirements based on a needs assessment of each research lab.

MENTORSHIP & MEMBER ENGAGEMENT

Regarding mentoring activities, the majority of the REU students have at least one graduate student mentor specific to their assigned IoT4Ag research project. This mentorship is established prior to the arrival of the summer REU student as the projects will have been identified beforehand. In addition, all students and postdoctoral fellows have a faculty advisor, particularly any students and/or fellows working on IoT4Ag research projects. Undergraduate students may have additional graduate students as mentors, specific to joint research projects.

This year, the annual retreat was held in person at University of California, Merced in June 2024. The following twelve (12) IPAB/ASAB members attended and participated in this year's retreat, either in-person or virtually: Rigo Rios (Latino Farmers Alliance), Gene McAvoy (Southwest Florida Research and Education Center), Ray Gaesser (Solutions from the Land), Barzin Moradi (California Dept. of Food and Agriculture), Clay Hine (Nordic Semiconductor), Keith Sandell (MARVIL, Inc), Nathan Dorn (Farm-ing), Kenny Lee (Aigen), Ryan McGibbon (Florida Dept. of Agriculture), Jordan Hesterman (FMC), Jeremy Groeteke (Syngenta) and Jim Ladlee (Penn State Ext). Seven of these members participated as panelists during the retreat: McAvoy (Joint Ops - Pests), McKibben (Joint Ops - Water), Groeteke, Moradi and Hesterman (Student Career Development), Ladlee and Rios (Stakeholder Engagement). In addition, two SAB members participated at the annual retreat - Dan Schmoldt (Joint Ops - Pests) and Pramod Khargonekar (Center Sustainability). Finally, the Center's Entrepreneurship Mentors, Andy Ziolkowski and York Eggleston, held an Entrepreneurship Start-Up's breakout session.

FINANCIAL MANAGEMENT

The University of Pennsylvania (Penn) is the prime recipient of the NSF award and in Year 4, Penn issued and fully executed the subcontracts to the three partner institutions. Funds were allocated to each institution as agreed upon with NSF, based on the functional budget categories – workforce development, diversity & culture of inclusion, and leadership / administration. The research functional budget allocation was based on the approved budgeted contributions of faculty research at each partner institution for projects selected in the renewal or new proposal process. The research funds were further sub-allocated to each of the three Thrusts. **Table 4I.1** below shows the allocation of the NSF award for Year 3 to each partner institution.

Table 4I.1. Institutional Distribution of Current Award Year Budget (Center-Generated)

Institution	Direct Cash Support	Associated Projects	Total Cash & Associated Project	% of Direct Cash	% of Associated Projects
University of Pennsylvania	$2,710,732	$0	$2,710,732	44.6%	0%
Purdue University	$1,119,717	$0	$1,119,717	18.4%	0%
University of California, Merced	$878,751	$5,316,253	$6,195,004	14.5%	100%
University of Florida	$1,313,163	$0	$1,313,163	21.6%	0%
Arizona State University	$50,000	$0	$50,000	0.8%	0%
Total	**$6,072,363**	**$5,316,253**	**$11,388,616**	**100.0%**	**100.0%**

Penn is also the recipient of the industry / practitioner membership fees. For Year 4, the fees have been collected and saved in a separate account. As of June 30, 2024, sixteen (1) organizations paid fees for a total of $127,000, with an additional $48,500 promised by August 30, 2024 and an additional $11,500 in in-kind contributions to join or renew their membership to be a member of the Industrial / Practitioner Advisory Board (IPAB). During this past summer (2024), the IPAB members submitted a proposal for the use of these funds that the IPAB members are currently reviewing and discussing.

Table 4I.2 below lists the Year 4 history of ERC funding of the Center and for this year, IoT4Ag has the base NSF award as well as supplemental funds awarded for student wellness activities.

Table 4I.2. History of ERC Funding of the Center (Center-Generated)

Award Number	Award Type	Award Title	Year of Award	Award Duration	Amount	Status	Final Report Approved?
EEC-1941529	Supplement (Veterans Supplement)	NSF Engineering Research Center for the Internet of Things for Precision Agriculture	YR4	1 Year	$69,363	Awarded	N/A
EEC-1941529	Supplement (Travel Award)	NSF Engineering Research Center for the Internet of Things for Precision Agriculture	YR4	1 Year	$3,000	Awarded	N/A
EEC-1941529	Supplement (Student Wellness)	NSF Engineering Research Center for the Internet of Things for Precision Agriculture	YR1	1 Year	$8,100	Awarded	N/A
EEC-1941529	Base	NSF Engineering Research Center for the Internet of Things for Precision Agriculture	YR1	5 Years	$26,000,000	Awarded	N/A
Total					**$26,080,463**		

The following **Table 4I.3** shows the actual (Year 1, Year 2 and Year 3), projected (Year 4), and committed (Year 5) cost share per partner institution across all five years. Due to the timing of the reporting year, ending June 30, 2024, we anticipate that the total cost share expenses will be higher than the amount reported below.

Table 4I.3. Cost Sharing by Institution (Center-Generated)

Institution	Award Year 1	Award Year 2	Award Year 3	Award Year 4	Award Year 5	YRs 1-5 Cumulative Transferred to ERC Account
	Actual	Actual	Actual	Projected	Committed	
University of Pennsylvania	$364,409	$393,979	$272,250	$960,720	$554,947	$2,546,305
Purdue University	$110,865	$175,970	$303,914	$138,470	$182,281	$911,500
University of California, Merced	$49,502	$123,481	$121,276	$2,989	$134,065	$431,313
University of Florida	$0	$167,711	$112,563	$64,956	$200,789	$546,019
Total	**$524,776**	**$861,141**	**$810,003**	**$1,167,135**	**$1,072,082**	**$4,435,137**

Institution	Award Year 6	Award Year 7	Award Year 8	Award Year 9	Award Year 10	All Years Cumulative Transferred to ERC Account
	Committed	Committed	Committed	Committed	Committed	
University of Pennsylvania	564,946	564,946	564,946	376,631	244,810	2,316,279
Purdue University	224,949	224,943	224,962	149,965	97,479	922,298
University of California, Merced	134,065	134,065	134,065	89,377	58,095	549,667
University of Florida	231,363	231,363	231,363	154,242	100,257	948,588
Total	**1,155,323**	**1,155,317**	**1,155.336**	**770,215**	**500,641**	**4,736,832**

For Year 4, IoT4Ag has not received any international funding nor has engaged in any international collaborations. **Tables 4I.4 and 4I.5** are not included in this report because there are no international partner universities or funding collaborative activities in Year 4.

The following table presents the unexpended or residual balance at the end of the reporting Year 4 for the period of September 1, 2022, to June 30, 2024. Please note that due to the timing of the reporting period, ending June 30, 2024, we anticipate that the committed and encumbered funds will be actualized by the end of the award year and upon receipt of our subaward invoices.

Table 4I.6. Unexpended Residual in the Current Award and Proposed Award Year (Center-Generated)

	Previous Award Year to Current Award Year	Current Award Year to Proposed Award Year
Total Unexpended Residual Funds	**$2,058,965**	**$1,619,079**
NSF	$3,365,834	$1,181,129
Industry	$280,950	$437,950
Committed, Encumbered, Obligated Funds**	**$3,646,784**	**$1,619,079**
NSF	$3,365,834	$1,181,129
Industry	$280,950	$437,950
Residual Funds Without Specified Use	**$0**	**$0**
NSF	$0	$0
Industry	$0	$0

*Includes residual funds carried forward from previous year.
**Includes full unexpended subcontract commitments

The noted residual for Year 4 is attributed to timing issues related to invoicing. Although subcontractor expenses through May 31st are included in current expenses, June 30th is the end of the fiscal year for our partners and will delay receipt of July/August invoices until after August

31st. Many summer expenses for the Annual Meeting, such as participant costs are included in those delayed invoices. This data has been presented at the weekly Site Directors meetings and our Business Administrator is working with her counterparts at our partner institutions to address these invoicing issues.

For this renewal report, below are the IoT4Ag major expenditures from the prior 3 years:

- **University of Pennsylvania**
  - **Semi-automatic screen printer:** This tool is used to screen print metal inks to manufacture low-cost biodegradable sensors at sufficient volume for field tests.
  - **Nanoimprint lithography tool:** This tool is used for the fabrication of optical metasurfaces for leaf sensors on flexible and biodegradable substrates using custom nanocrystal inks. The tool allows for optimizing nanopatterning uniformity through pressure, temperature and vacuum control.
  - **Semi-automated die bonder:** This tool is used to attach semiconductor chips to printed sensors. It will be used to attach resonators to paper-based soil sensors and silicon ICs to various active sensors.
  - **Headwall Imaging Spectrometer:** This hyperspectral camera will be mounted on an automated robotic imaging system that will be used to characterize the spectral response of leaf sensors in the field.
  - **Ocean Optics spectrometer:** This benchtop tool is used to characterize the spectral shift of leaf sensors in response to changes in humidity, temperature, and other stimuli. It is complementary to the Headwall unit that is mounted on the robotics platform.
  - **Benchtop plasma system:** For surface functionalization of templates for imprint lithography for patterning of leaf sensors, as well as plasma treatment of biodegradable substrates prior to patterning.
  - **Zeiss optical microscope:** This microscope is used for inspection of sensor devices at various steps of fabrication for leaf sensors and soil sensors, and to conduct multi-day experiments to visualize the effects of stomata transpiration with sensors attached.
  - **Ouster Lidars:** These devices were used to outfit drones used for mapping and to build a sensor suite shipped from Penn to UC Merced.
  - **GPU workstations:** These are used for deep learning to support work related to semantic mapping of tree crops. Workstations are also being used to develop perception algorithms using event-based cameras that can map and navigate highly unstructured environments under harsh lighting conditions
- **University of Florida**
  - **Nano-Hyperspec VNIR:** This is a hyperspectral camera which can photograph an object and give detailed information about its color outside of the normal RGB range. This project utilizes a moving mirror and the hyperspectral camera to differentiate between healthy and sick plants while young and still growing.
  - **Parrot ANAFI:** drone systems that collect high-resolution RGB imagery to augment the hyperspectral imagery being collected. This enables improvements in data collection practices through better annotation, alignment and augmented data sets.
  - **Jackal J100 Robotic Research:** This is a ground robot designed for agricultural applications. It is used for inspection, imaging, and sampling in crop fields, as well as allows testing of the wireless charging system (a research focus) on the same model used elsewhere in the research consortium.

- **Purdue University**
  - **Clearpath Robotics Jackal:** These components integrated together create three AgBot platforms for in-row and under canopy crop monitoring, assessment, and physical sampling.
  - **Headwall SWIR sensor:** ll spectrum capability to monitor chemistry-based responses in plants, as well as new sensor technology developed at University of Pennsylvania.
- **University of California, Merced**
  - **Spectral Evolution RS8800:** Full range (VSWIR 350-2500 nm) portable spectroradiometer to make leaf-level and canopy-level reflectance measurements of plants for calibration and tuning of sensor development and characterization of plan biophysical condition and traits.
  - **Micasense Altum PT:** Mounted on a DJI M300 drone with RTK capability it enables us to collect data across the visible, near infrared and thermal infrared regions of the spectrum with seamless integration, enabling phenotyping at field scale and drought stress detection.
  - **DJI Phantom 4Pro:** Drone, equipped with a multiband camera module to capture aerial imagery for assessing crop health and managing vegetation.
  - **B& W TEK Raman Spectrometer:** Raman spectroscopy is an analytical technique used to identify molecules and study the vibrational, rotational, and other low-frequency modes in a system. We use this technique to identify the water content in pistachio and almond trees associated with the specific molecular compositions of their leaves.
  - **Handheld Photosynthesis System (CI-340):** This instrument helps investigate the plant response to different fertilization rates and crop management techniques, environmental stresses such as abiotic stress, and plant disease symptoms. It provides vital information for the early detection of plant stresses.
  - **Clearpath Husky:** Small size robotic platform to perform data collection at scale in orchards by carrying different senor payloads (e.g., thermal imaging collection to infer water stress in almonds and pistachios).
  - **Farm-ng Amiga with Kinova arm (2x):** Larger scale robotic platforms to perform cooperative data collection and plant manipulation (e.g., specimen collection) at scale and size beyond what is possible with the Clearpath Husky.

Below is a trend chart showing the historical increase of funding from Year 1 through Year 4.



Figure 4I.1. Funding trend chart from Year 1 to Year 4 (Center-Generated)

IOT4AG SELF-SUFFICIENCY BUSINESS PLAN

EXECUTIVE SUMMARY

IoT4Ag, The Internet of Things for Precision Agriculture is a research, education, and innovation

Vision: *to ensure food, energy, and water security by advancing technology to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment*.

Mission: *to create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.*

IoT4Ag was launched in September 2020 with U.S. federal support under the National Science Foundation (NSF) Engineering Research Center program. Today, the IoT4Ag mission continues. The Center is building on its achievements and educating people, fostering communities, and advancing the technologies and systems needed to ensure food, energy, and water security in an ever-changing world.

ORGANIZATION

IoT4Ag is an academia-industry-government partnership, bringing together diverse participants in research, education, inclusion, and innovation. The Center unites an interdisciplinary cadre of faculty, students, and staff from the University of Pennsylvania, Purdue University, the University of California, Merced, and the University of Florida, and in evaluation and assessment, from Arizona State University; with small to large industry members; local, regional, and state education, inclusion, government, and innovation partners; and growers, Ag industry professionals, and grower associations. IoT4Ag members are experts in agronomy, agricultural engineering and economics, and environmental science and in the science and engineering of physical and cyber systems. It is an excellent team positioned to create and translate IoT4Ag technologies and systems and to continually develop and deliver IoT4Ag-E^3 programs, i.e., to Excite, Educate, and Enable K-12 to university students and agricultural and technology professionals and educators, including diverse groups of people in learning, creating, and practicing precision agriculture technologies. IoT4Ag has built a network of stakeholders and advisors who will continue to be engaged to ensure the impact of the Center's work.

IOT4AG PRODUCTS

IoT4Ag is creating agricultural technologies, systems, and testbeds and inclusive educational programs to deliver on the future of agriculture.

1. ***New Agricultural Technologies and Integrated Systems*** – *Inventing* the technologies and systems needed now and in the future

   IoT4Ag continues to invent leading-edge Ag-Tech hardware and software platform technologies spanning multi-mode, low-cost, distributable, plant and soil sensors; autonomous aerial- and ground-based robots; energy storage and delivery technologies for field-scale operations; Ag-specific edge and backhaul communications; AI-driven digital twins of row

and tree crops; and human-centered decision-Ag interfaces for agricultural management. IoT4Ag technologies are synergistically combined in integrated systems to sustainably manage row and tree crops. Our platform technologies and integrated systems are positioned for agility and responsiveness to provide solutions to meet urgent needs in a changing world, e.g., technologies and systems responsive to the sudden onset of drought, the rise of herbicide resistant weeds, or the appearance of a new disease or pest attacking a particular crop. IoT4Ag continues to build partnerships to manufacture hardware and to house open-source algorithms and data sets and to engage research, industry, and stakeholder communities in inventing, developing, deploying, translating, and practicing Ag-Tech.

2. **Ag-Tech Testbed User Facilities and Data Repositories** – *Deploying* Ag-Tech engineering systems that address societal challenges

   IoT4Ag testbeds go beyond Ag-Extension and serve as regional, national, and global resources to bring academia, government, and industry "users" to IoT4Ag to rapidly and affordably test technologies at agricultural scales. IoT4Ag testbeds are equipped with reference sensors, agricultural machinery, and communication technologies and integrate machine learning/AI datasets that capture the field history, i.e., management practices and data as crops rotate in experimental trials. Akin to the NSF National Nanotechnology Coordinated Infrastructure (NNCI) or the NSF Platforms for Advanced Wireless Research (PAWR), external users will submit experimental packages for testing in the IoT4Ag testbeds. IoT4Ag testbed facilities will allow users to test minimum viable products, as is common in tech industries, but at agricultural field scale to enable and establish a robust, rapid Ag-Tech community of inventors and developers. These testbeds will include certain levels of access to farm lands, environmental sensor data, reference sensor suites, and data pipelines needed for baseline experimentation. The IoT4Ag Ag-Tech testbeds provide a particular opportunity for Ag-Tech startups and small companies that don't have access to cropping systems at field scale.

3. **IoT4Ag-E^3 Programs** – *Disseminating* Ag and Tech knowledge and *Empowering* people

   a. **Excite – Tech Meets Ag Curricula –** IoT4Ag continues to create and deliver educational kits and lessons to build science, technology, and agriculture literacy in K-12 students. The curricula excite students by making learning fun and by connecting science and technology to food and to the use of technology for addressing the grand challenge of food, energy, and water security and other societal challenges accelerated by climate change. The curricula have been deployed across the U.S. to diverse groups of students and is online for global accessibility. IoT4Ag continues to grow its partnerships with educational organizations and serves as Content experts, allowing organizations to own/lead the creation of and to distribute curricula to ensure compliance with local/state educational standards and requirements or to meet the needs of different populations of learners.

   b. **Educate for an Inclusive World –** IoT4Ag is educating community college, undergraduate, and graduate students and postdoctoral fellows for the workforce, prepared to innovate and practice precision Ag-Tech and technologies for adjacent industries. To support a diverse student body and workforce of the future, IoT4Ag established the Pathway to PhD Program (PPP), a signature initiative of the Center. PPP is providing online education and a national network of mentors from different regions, disciplines, and experiences to demystify, guide, and prepare mentees for the U.S. graduate education and

fellowship application processes. PPP is open to anyone anywhere and uniquely provides hands-on writing and individual feedback on research and personal statements.

c. **Enable Professional Advancement –** IoT4Ag has and continues to build a network of long-term trusted relationships with growers, Ag industry professionals, and grower associations, including tech-interested Ag professionals who are members of the IoT4Ag Ag-Systems Advisory Board and those who engage in IoT4Ag professional outreach and Ag extension. Earning the trust of the stakeholder community is key to their successful engagement in IoT4Ag educational programs and ultimately in the adoption of Ag technologies. IoT4Ag also established the Minority Serving Institution - Historically Black Colleges and Universities (MSI-HBCU) Partners Network Program to host faculty at IoT4Ag research laboratories. The Program expands the research, education, and resource base for participating faculty and their students to share with their peers and home institutions, and in turn, IoT4Ag and its host labs learn from the participants about their research and teaching expertise and their institutions.

4. **Innovation and Commercialization** – *Translating* IoT4Ag technologies and systems

   a. **IoT4Ag Center for Ag-Tech Innovation –** Entrepreneurship is an especially important avenue for entry of new Ag-Tech. To meet Ag-specific use cases, technologies and systems must be cost effective, where early-stage revenue makes for a great small business but is too small for big business. IoT4Ag is establishing a cohort of innovation mentors with Ag-Tech domain knowledge and is developing partnerships with and a brand trusted by Ag-Tech investors. The Center for Ag-Tech Innovation also takes advantage of the IoT4Ag Ag-Tech User Facilities to allow startup companies access to cropping systems at field scale to test and build data needed in proving their technologies.

   b. **IoT4Ag Innovation Ecosystem –** IoT4Ag has established and is growing its industrial practitioner advisory board of member companies and the Ag-systems advisory board of growers, grower agents, and grower associations. The IoT4Ag innovation ecosystem brings together companies of different sizes and from different sectors to create partnerships that translate technologies to practice. The ecosystem of companies is a "can't miss" network to belong to for companies working in Ag-Tech.

FINANCIAL PLANNING

IoT4Ag financial planning includes a diverse portfolio of funding instruments. The Center expects that no one instrument will sustain the IoT4Ag mission, team, and products. IoT4Ag's space is the agriculture sector, and while agriculture is essential to worldwide human health, it doesn't command the same industry investment as other sectors. IoT4Ag sustainability requires support from government and industry, and as IoT4Ag's vision is to ensure food, energy, and water security, it is responsive to the interests of and it is well positioned for funding by philanthropic organizations. In 2019, U.S. public agricultural research R&D funding was 64% from the federal government, 20% from state governments, and 16% from non-governmental entities, i.e., from both industry and charitable foundations (USDA, 2022). IoT4Ag is building its brand and relationships to execute on product appropriate funding by government, industry, and philanthropic organizations.

1. ***New Agricultural Technologies and Integrated Systems*** – *Inventing* the technologies and systems needed now and in the future

Federal Funding: IoT4Ag is known for IoT hardware and software technology and system innovation for Ag-Tech. As the Center grows under NSF ERC funding, it is positioning itself for future federal funding, appropriately from other directorates within the NSF (e.g., the TIPS directorate or Mid-Scale Research Infrastructure program) and from the USDA (e.g., National Institute of Food and Agriculture initiatives). As an example, IoT4Ag and the USDA share common interests in IoT for precision Ag and in inclusive Ag education. IoT4Ag recently met with USDA Agricultural Research Service (ARS) national program leaders and we are working on a plan of future presentations and workshops to get to know each other toward building partnerships and future funding.

State Funding: IoT4Ag will pursue state funding. Agriculture is vital to California's, Florida's, Indiana's, and Pennsylvania's state economies, significant to state GDP and to jobs. IoT4Ag core partner state governments are investing in agricultural innovation and are the predominant funder of agriculture extension. In 2023, Pennsylvania launched and IoT4Ag/Penn is a member of the Pennsylvania Advanced Agriculture Cross-Sector Collaborative, a public-private partnership committed to PA's agricultural industries. The 2024-2025 PA budget includes a new $10 million Agricultural Innovation Grant Program. In 2022, UC Merced was designated an agricultural experiment station, positioning Merced for UC Agriculture and Natural Resource funding. Florida is launching "Florida Spark", a state-funded Ag-Tech incubator network, with hubs that provide incubator space, innovation education/training, and shared services to entrepreneurs and innovators. The Indiana Economic Development Corporations sponsors a vigorous AgBioscience initiative for innovation and workforce development.

Industry Funding: IoT4Ag is working with its Industrial Practitioner Advisory Board (IPAB) to plan for IoT4Ag self-sufficiency. The IPAB Executive Committee drafted and is now socializing amongst member companies options for an "IoT4Ag Innovation Fund" recognizing that "… National Science Foundation (NSF) funding is finite, so there will need to be funding mechanisms to help IoT4Ag become self-sufficient." The draft plan includes a process for investment of membership dues to provide additional funding to priority projects, for additional member capital investment, for capital to support business development, and for a fund governance structure.

Foundations and Philanthropic Individuals and Organizations: IoT4Ag's research is well positioned for funding from foundations with shared interests in agricultural innovation. The Center will explore funding opportunities through foundations such as the Bill and Melinda Gates Foundation, the Ida and Robert Gordon Foundation, or the Bezos Earth Fund and will work with university offices with expertise in applying for foundation funding. IoT4Ag has core academic partner institutions with alumni particularly interested in environmental and food system sustainability and in ensuring the health and well-being of people. IoT4Ag will work with administrators and alumni relations to identify donors interested in supporting IoT4Ag. IoT4Ag will also work to build relationships with philanthropic individuals and organizations who are interested in giving to sustain the Center's mission.

2. **Ag-Tech Testbed User Facilities and Data Repositories** – *Deploying* Ag-Tech engineering systems that address societal challenges

   Federal – State – Industry Funding/User Fees: IoT4Ag will propose to establish an Ag-Tech Testbed user network to the NSF and USDA modeled on other national research infrastructure networks (e.g., USDA's Farm of the Future and NSF NNCI, PAWR, and Mid-scale RI-1/RI-

2). As described above, the facilities are equipped with hardware and software to support Ag-Tech innovation. Federal funding will be requested to partially support the infrastructure costs to upkeep instrumentation and data sets and to pay the staff that maintain the tools and educate users to establish experimental packages that take advantage of the advanced hardware and software. We will also explore user fee structures, well established in user facility networks, to partially support the costs of instrumentation and data sets. The Center will also explore state funding, consistent with its support of Ag Extension, to create advanced stakeholder education and support Ag-Tech testbed fields. IoT4Ag will also create a nationwide open-source repository of Ag-Tech software assets and large datasets, and is looking at the NSF Pathways to Enable Open-Source Ecosystems (POSE) solicitation as well as industry partnerships with "big data" companies such as Amazon, IBM, and Microsoft.

3. **IoT4Ag-E^3 Programs –** *Disseminating* Ag and Tech knowledge and *Empowering* people

   a. **Excite – Tech Meets Ag Curricula –** IoT4Ag will apply for federal (e.g., NSF and USDA), state (e.g., Farm to School/Ag in the Classroom grants), and regional (e.g., Philadelphia's Fairmount Water Works) funding as well as industry (e.g., Bayer Fund: STEM Education Grants) and foundation funding to support national, state, and regional dissemination of IoT4Ag curricula. IoT4Ag will also work with educational partners and support schools, camps, museums, youth organizations (e.g., 4-H, FFA), and teachers apply for direct funding to support bringing IoT4Ag curricula and agricultural and technology education to their students.

   b. Educate for an Inclusive World – The Center will apply for federal funds to support scaling of the PPP program and building a national network of trained mentors. IoT4Ag will apply to the Broadening Participation in Engineering (BPE) Program, Track 3: Inclusive Mentoring Hubs (IMHubs).

   c. Enable Professional Advancement – IoT4Ag will apply for NSF funding through the Research Experience and Mentoring program to support IoT4Ag's MSI-HBCU Partners Network Program.

4. **Innovation and Commercialization** – *Translating* IoT4Ag technologies and systems

   a. IoT4Ag Center for Ag-Tech Innovation – IoT4Ag students, faculty, and staff are, as appropriate, will continue to participate in I-Corps programs, launch start-up companies, and pursue SBIR/STTR funding with industry members. The Center will work with existing and future IPAB members, as described above, to allocate funds to support business development of center technologies and to support engagement with venture capital firms.

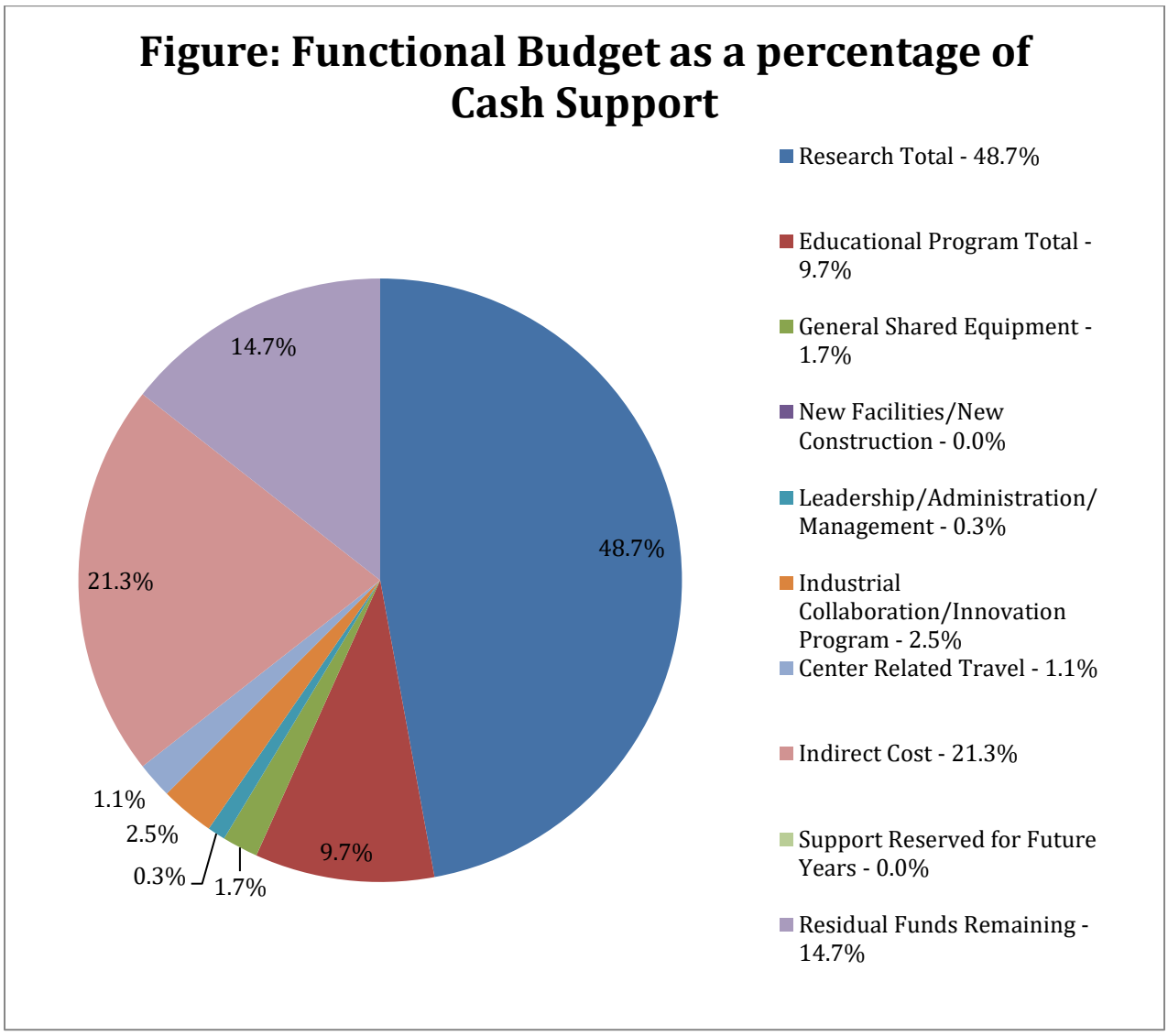
   b. IoT4Ag Innovation Ecosystem – IoT4Ag will build its innovation ecosystem of industry and stakeholder members. Industry members will continue to fund their participation. IoT4Ag will include support of the stakeholder community in federal and state funding applications, as described above, and apply for federal, state, regional, and foundation funding to support agricultural professional participation in IoT4Ag.

IoT4Ag will reinvest income from licensing revenue earned through Center innovation and commercialization activities to sustain IoT4Ag's research, education, inclusion, and innovation programs. IoT4Ag universities are also committed to continued financial support of IoT4Ag (**see Appendix XIV: Supplemental Materials**).

ERCWEB TABLE 21: CURRENT AWARD YEAR FUNCTIONAL BUDGET

Table: Current Award Year Functional Budget			
Function	**Cash Support**		**Cash Support Budget Total**
	Unrestricted Cash (Core Projects)	**Restricted Cash (Sponsored Projects)**	
Engineering Workforce Development	$252,129	$0	$252,129
Thrust 1: Agricultural Sensors Systems	$2,813,847	$0	$2,813,847
Thrust 2: Communication and Energy Systems	$1,295,221	$0	$1,295,221
Thrust 3: Agricultural Response Systems	$1,019,135	$0	$1,019,135
Research Total	**$5,380,332**	**$0**	**$5,380,332**
Educational Program Total	$1,068,551	$0	$1,068,551
General Shared Equipment	$191,982	$0	$191,982
New Facilities/New Construction	$0	$0	$0
Leadership/Administration/Management	$38,056	$0	$38,056
Industrial Collaboration/Innovation Program	$274,138	$0	$274,138
Center Related Travel	$121,158	$0	$121,158
Indirect Cost	$2,349,986	$0	$2,349,986
Functional and Educational Budget Total	**$4,043,871**	**$0**	**$4,043,871**
Support Reserved for Future Years	N/A	N/A	$0
Residual Funds Remaining	$1,619,079	$0	$1,619,079
Cash Support Budget Total	**$11,043,282**	**$0**	**$11,043,282**
Associated Project Support Total	**N/A**	**N/A**	**$5,892,558**
Grand Total (Cash Support + Associated Project Support)	**$11,043,282**	**$0**	**$16,935,840**

ERCWEB FIGURE 13: FUNCTIONAL BUDGET AS A PERCENTAGE OF DIRECT SUPPORT



ERCWEB TABLE 22: CURRENT AWARD YEAR EDUCATION FUNCTIONAL BUDGET

Table: Current Award Year Education Functional Budget			
Education Programs	**Cash Support**		**Cash Support Budget Total**
	Unrestricted Cash OR Core Projects	**Restricted Cash OR Sponsored Projects**	
Precollege Education Activities	$369,798	$0	**$369,798**
University Education	$182,139	$0	**$182,139**
Student Leadership Council	$0	$0	**$0**
Young Scholars	$0	$0	**$0**
REU	$112,099	$0	**$112,099**
RET	$36,044	$0	**$36,044**
Assessment	$50,000	$0	**$50,000**
Community College activities	$0	$0	**$0**
Other	$318,471	$0	**$318,471**
Education Program Total	**$1,068,551**	**$0**	**$1,068,551**

ERCWEB TABLE 23: SOURCES OF SUPPORT

Table: Sources of Support							
Sources of Support	**Sep 1, 2020 - Aug 31, 2021**	**Sep 1, 2021 - Aug 31, 2022**	**Sep 1, 2022 - Aug 31, 2023**	**Sep 1, 2023 - Aug 31, 2024**			**Cumulative Total [1]**
				Received	**Promised**	**Total**	
Unrestricted Cash							
Government							
NSF Funding							
NSF ERC Base Award	$3,500,000	$4,500,000	$6,000,000	$6,000,000	$0	$6,000,000	$20,000,000
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$3,500,000**	**$4,500,000**	**$6,000,000**	**$6,000,000**	**$0**	**$6,000,000**	**$20,000,000**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$3,500,000**	**$4,500,000**	**$6,000,000**	**$6,000,000**	**$0**	**$6,000,000**	**$20,000,000**
Industry							
U.S. Industry	$59,750	$56,200	$131,000	$97,000	$30,000	$127,000	$373,950
Foreign Industry	$0	$500	$32,500	$30,000	$0	$30,000	$63,000
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$59,750**	**$56,700**	**$163,500**	**$127,000**	**$30,000**	**$157,000**	**$436,950**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Venture Capitalist	$0	$1,000	$0	$0	$0	$0	$1,000
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$1,000**	**$0**	**$0**	**$0**	**$0**	**$1,000**
Total Unrestricted Cash	**$3,559,750**	**$4,557,700**	**$6,163,500**	**$6,127,000**	**$30,000**	**$6,157,000**	**$20,437,950**
Restricted Cash							
NSF Funding							
NSF ERC Program Special Purpose Awards and Supplements	$0	$8,102	$0	$72,363	$0	$72,363	$80,465
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$8,102**	**$0**	**$72,363**	**$0**	**$72,363**	**$80,465**
Restricted Cash - Non Translational							
Government							
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University							
U.S. University	$524,776	$861,142	$810,003	$1,167,135	$0	$1,167,135	$3,363,056

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$524,776**	**$861,142**	**$810,003**	**$1,167,135**	**$0**	**$1,167,135**	**$3,363,056**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Restricted Cash - Non Translational	**$524,776**	**$861,142**	**$810,003**	**$1,167,135**	**$0**	**$1,167,135**	**$3,363,056**
Restricted Cash - Translational							
Government							
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Restricted Cash - Translational	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Restricted Cash	**$524,776**	**$869,244**	**$810,003**	**$1,239,498**	**$0**	**$1,239,498**	**$3,443,521**
Multi-year support carried over from prior years							
Government							
Other U.S. Government (Not NSF)	$0	$0	$0	$0	N/A	$0	N/A
State Government	$0	$0	$0	$0	N/A	$0	N/A
Local Government	$0	$0	$0	$0	N/A	$0	N/A
Foreign Government	$0	$0	$0	$0	N/A	$0	N/A
Quasi-government research organization	$0	$0	$0	$0	N/A	$0	N/A
TOTAL GOVT Multi-year Support from Prior Years	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**
Industry							
U.S. Industry	$0	$0	$0	$0	N/A	$0	N/A
Foreign Industry	$0	$0	$0	$0	N/A	$0	N/A
Industrial Association	$0	$0	$0	$0	N/A	$0	N/A
TOTAL INDUSTRY Multi-year Support from Prior Years	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Other							
Private Foundation	$0	$0	$0	$0	N/A	$0	N/A
Medical Facility	$0	$0	$0	$0	N/A	$0	N/A
Non Profit	$0	$0	$0	$0	N/A	$0	N/A
Venture Capitalist	$0	$0	$0	$0	N/A	$0	N/A
Other	$0	$0	$0	$0	N/A	$0	N/A
TOTAL OTHER Multi-year Support from Prior Years	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**
Total Multi-year support carried over from prior years	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**
Residual Funds carried over from prior years [2]							
Government							
NSF Funding							
NSF ERC Base Award	$0	$1,709,207	$1,941,515	$3,365,834	N/A	$3,365,834	N/A
Other NSF (Not ERC Program)	$0	$0	$0	$0	N/A	$0	N/A
TOTAL NSF Residual Funds from Prior Years	**$0**	**$1,709,207**	**$1,941,515**	**$3,365,834**	**N/A**	**$3,365,834**	**N/A**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	N/A	$0	N/A
State Government	$0	$0	$0	$0	N/A	$0	N/A
Local Government	$0	$0	$0	$0	N/A	$0	N/A
Foreign Government	$0	$0	$0	$0	N/A	$0	N/A
Quasi-government research organization	$0	$0	$0	$0	N/A	$0	N/A
TOTAL GOVT Residual Funds from Prior Years	**$0**	**$1,709,207**	**$1,941,515**	**$3,365,834**	**N/A**	**$3,365,834**	**N/A**
Industry							
U.S. Industry	$0	$59,750	$117,450	$280,950	N/A	$280,950	N/A
Foreign Industry	$0	$0	$0	$0	N/A	$0	N/A

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Industrial Association	$0	$0	$0	$0	N/A	$0	N/A
TOTAL INDUSTRY Residual Funds from Prior Years	**$0**	**$59,750**	**$117,450**	**$280,950**	**N/A**	**$280,950**	**N/A**
University							
U.S. University	$0	$0	$0	$0	N/A	$0	N/A
Foreign University	$0	$0	$0	$0	N/A	$0	N/A
TOTAL UNIVERSITY Residual Funds from Prior Years	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**
Other							
Private Foundation	$0	$0	$0	$0	N/A	$0	N/A
Medical Facility	$0	$0	$0	$0	N/A	$0	N/A
Non Profit	$0	$0	$0	$0	N/A	$0	N/A
Venture Capitalist	$0	$0	$0	$0	N/A	$0	N/A
Other	$0	$0	$0	$0	N/A	$0	N/A
TOTAL OTHER Residual Funds from Prior Years	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**
Total Residual Funds carried over from prior years [2]	**$0**	**$1,768,957**	**$2,058,965**	**$3,646,784**	**N/A**	**$3,646,784**	**N/A**
Associated Projects [3]							
NSF Funding							
NSF ERC Program	$0	$0	$0	N/A	N/A	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	N/A	N/A	$576,305	$576,305
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$576,305**	**$576,305**
Associated Projects - Non Translational [3]							
Government							
Other U.S. Government (Not NSF)	$0	$0	$0	N/A	N/A	$0	$0
State Government	$0	$0	$0	N/A	N/A	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Local Government	$0	$0	$0	N/A	N/A	$0	$0
Foreign Government	$0	$0	$0	N/A	N/A	$0	$0
Quasi-government research organization	$0	$0	$0	N/A	N/A	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	N/A	N/A	$0	$0
Foreign Industry	$0	$0	$0	N/A	N/A	$0	$0
Industrial Association	$0	$0	$0	N/A	N/A	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$0**	**$0**
University							
U.S. University	$0	$0	$0	N/A	N/A	$0	$0
Foreign University	$0	$0	$0	N/A	N/A	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	N/A	N/A	$0	$0
Medical Facility	$0	$0	$0	N/A	N/A	$0	$0
Non Profit	$0	$0	$0	N/A	N/A	$0	$0
Venture Capitalist	$0	$0	$0	N/A	N/A	$0	$0
Other	$10,000	$60,000	$249,825	N/A	N/A	$250,509	$570,334
TOTAL OTHER FUNDING	**$10,000**	**$60,000**	**$249,825**	**N/A**	**N/A**	**$250,509**	**$570,334**
Total Associated Projects - Non Translational	**$10,000**	**$60,000**	**$249,825**	**N/A**	**N/A**	**$250,509**	**$570,334**
Associated Projects - Translational [3]							
Government							
Other U.S. Government (Not NSF)	$0	$0	$0	N/A	N/A	$0	$0
State Government	$0	$0	$0	N/A	N/A	$0	$0
Local Government	$0	$0	$0	N/A	N/A	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Foreign Government	$0	$0	$0	N/A	N/A	$0	$0
Quasi-government research organization	$0	$0	$0	N/A	N/A	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	N/A	N/A	$0	$0
Foreign Industry	$0	$0	$0	N/A	N/A	$0	$0
Industrial Association	$0	$0	$0	N/A	N/A	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$0**	**$0**
University							
U.S. University	$0	$0	$0	N/A	N/A	$0	$0
Foreign University	$0	$0	$0	N/A	N/A	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**N/A**	**N/A**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	N/A	N/A	$0	$0
Medical Facility	$0	$0	$0	N/A	N/A	$0	$0
Non Profit	$0	$0	$0	N/A	N/A	$0	$0
Venture Capitalist	$0	$0	$0	N/A	N/A	$0	$0
Other	$0	$0	$5,051,903	N/A	N/A	$5,065,744	$10,117,647
TOTAL OTHER FUNDING	**$0**	**$0**	**$5,051,903**	**N/A**	**N/A**	**$5,065,744**	**$10,117,647**
Total Associated Projects - Translational	**$0**	**$0**	**$5,051,903**	**N/A**	**N/A**	**$5,065,744**	**$10,117,647**
Total Associated Projects	**$10,000**	**$60,000**	**$5,301,728**	**N/A**	**N/A**	**$5,892,558**	**$11,264,286**
Value of New Construction							
Government							
NSF Funding							
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of New Construction	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Value of Equipment							

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Government							
NSF Funding							
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$0	$3,500	$1,500	$2,500	$0	$2,500	$7,500
Foreign Industry	$0	$500	$0	$5,000	$0	$5,000	$5,500
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$4,000**	**$1,500**	**$7,500**	**$0**	**$7,500**	**$13,000**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Total Value of Equipment	**$0**	**$4,000**	**$1,500**	**$7,500**	**$0**	**$7,500**	**$13,000**
Value of New Facilities in Existing Buildings							
Government							
NSF Funding							
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of New Facilities in Existing Buildings	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Value of Visting Personnel							
Government							
NSF Funding							
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of Visting Personnel	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Value of Other Assets							
Government							
NSF Funding							
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry							
U.S. Industry	$18,841	$16,800	$0	$0	$0	$0	$35,641
Foreign Industry	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$18,841**	**$16,800**	**$0**	**$0**	**$0**	**$0**	**$35,641**
University							
U.S. University	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Sep 1, 2020 - Aug 31, 2021	Sep 1, 2021 - Aug 31, 2022	Sep 1, 2022 - Aug 31, 2023	Sep 1, 2023 - Aug 31, 2024			Cumulative Total [1]
				Received	Promised	Total	
Foreign University	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other							
Private Foundation	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of Other Assets	**$18,841**	**$16,800**	**$0**	**$0**	**$0**	**$0**	**$35,641**
Total In-Kind Support, All Sources	**$18,841**	**$20,800**	**$1,500**	**$7,500**	**$0**	**$7,500**	**$48,641**
Total Cash Support, All Sources [2]	**$4,084,526**	**$7,195,901**	**$9,032,468**	**$11,013,282**	**$30,000**	**$11,043,282**	**$23,881,471**
Percent Non-ERC Program Cash	**14%**	**14%**	**12%**	**14%**	**100%**	**15%**	**16%**
Total Cash + In-Kind	**$4,103,367**	**$7,216,701**	**$9,033,968**	**$11,020,782**	**$30,000**	**$11,050,782**	**$23,930,112**
Grand Total (Cash + In-Kind + Associated Projects)	**$4,113,367**	**$7,276,701**	**$14,335,696**	**$16,913,340**	**$30,000**	**$16,943,340**	**$35,194,398**

[1] - No Residual amounts or multi-year support carried over from prior years are included in the Cumulative Total column because the funds are by definition included in the year in which they were received.

[2] - Cash Total = The sum of Unrestricted Cash, Restricted Cash, and Residual Funds for a particular NSF Award Year, but NOT Support for Associated Projects. This cash amount in Sources of Support Table is also the total for the 'Expenditure' column pertaining to the same Award Year in Annual Expenditures Table.

[3] - Starting in 2023, Associated Project support amounts are collected as Total Support and are not collected as Promised and Received amounts.

ERCWEB TABLE 24: ANNUAL EXPENDITURES AND BUDGETS

Table: Annual Expenditures and Budgets

Cash Support	**Sep-01-2020 - Aug-31-2021**	**Sep-01-2021 - Aug-31-2022**	**Sep-01-2022 - Aug-31-2023**	**Sep-01-2023 - Aug-31-2024**	**Proposed Budget - Next Award Year**
Cash Support (All Sources)	**$4,084,526**	**$5,426,944**	**$6,973,503**	**$7,396,498**	**N/A**
Multi-year Support brought forward from Prior Year (All Sources)	**$0**	**$0**	**$0**	**$0**	**N/A**
Residual Funds brought forward from Prior Year (All Sources)	**$0**	**$1,768,957**	**$2,058,965**	**$3,646,784**	**N/A**
Total Cash Support	**$4,084,526**	**$7,195,901**	**$9,032,468**	**$11,043,282**	**N/A**

Expenses	**Sep-01-2020 - Aug-31-2021**	**Sep-01-2021 - Aug-31-2022**	**Sep-01-2022 - Aug-31-2023**	**Sep-01-2023 - Aug-31-2024**	**Proposed Budget - Next Award Year**
Salaries & Benefits					
A. Senior Personnel: PI/PD, Co-PIs, Faculty and Other Senior Associates	$321,167	$266,152	$202,882	$251,553	$96,932
B. Other Personnel	$373,456	$492,972	$537,916	$985,152	$908,550
Postdoctoral associates	$25,398	$50,221	$0	$89,579	$0
Other professionals (technician, programmer, etc.)	$180,236	$159,805	$187,276	$259,868	$281,550
Graduate Students	$154,972	$244,407	$310,097	$549,823	$627,000
Undergraduate students	$12,850	$38,539	$39,043	$79,982	$0
Secretarial - clerical	$0	$0	$0	$0	$0
Other	$0	$0	$1,500	$5,900	$0
C. Fringe Benefits	$152,897	$138,012	$122,615	$183,216	$83,595
Total Salaries & Benefits (A+B+C)	**$847,520**	**$897,136**	**$863,413**	**$1,419,921**	**$1,089,077**

Other Expenses					
D. Equipment	$30,911	$68,296	$18,970	$714,937	$0
E. Travel	$787	$39,264	$67,716	$163,551	$9,400
F. Participant Support	$17,697	$52,903	$21,150	$74,043	$36,000
G. Other Direct Costs	$883,445	$3,459,150	$3,581,852	$5,770,979	$3,959,281
H. Direct Costs Total (A through G)	**$1,780,360**	**$4,516,749**	**$4,553,101**	**$8,143,431**	**$5,093,758**
I. Indirect Costs	**$535,209**	**$620,187**	**$832,583**	**$1,280,772**	**$906,242**
TOTAL Expenditures and Budgets (A through I)	**$2,315,569**	**$5,136,936**	**$5,385,684**	**$9,424,203**	**$6,000,000**

Totals and Residuals	**Sep-01-2020 - Aug-31-2021**	**Sep-01-2021 - Aug-31-2022**	**Sep-01-2022 - Aug-31-2023**	**Sep-01-2023 - Aug-31-2024**	**Proposed Budget -**

					Next Award Year
Total Cash Support	**$4,084,526**	**$7,195,901**	**$9,032,468**	**$11,043,282**	**N/A**
J. TOTAL Expenditures and Budgets (A through I)	$2,315,569	$5,136,936	$5,385,684	$9,424,203	$6,000,000
K. Support Reserved for Future Years	$0	$0	$0	$0	N/A
L. Residual Funds Remaining	$1,768,957	$2,058,965	$3,646,784	$1,619,079	$0
Balance (Subtract J+K+L from Current Year Support)	**$0**	**$0**	**$0**	**$0**	**N/A**

[1] - For Centers in operation for more than five years.

ERCWEB TABLE 25: MODES OF SUPPORT BY INDUSTRY AND OTHER PRACTITIONER ORGANIZATIONS

See next page for the ERCWEB Table: Modes of Support by Industry and Other Practitioner Organizations

Table: Modes of Support, by Industry and Other Practitioner Organizations													
Organization	Sep 1, 2022 - Aug 31, 2023						Sep 1, 2023 - Aug 31, 2024						Promised Support
	Fees and Contributions	Sponsored Projects		Associated Projects		In-Kind Support	Fees and Contributions	Sponsored Projects		Associated Projects		In-Kind Support	
		Non-translational	Translational	Non-translational	Translational			Non-translational	Translational	Non-translational	Translational		
Industrial/Practitioner Member Organizations													
AgriBugs, LLC	$0	$0	$0	$0	$0	$1,000	$0	$0	$0	$0	$0	$2,500	$0
AgSensor Solutions	$1,000	$0	$0	$0	$0	$0	$1,000	$0	$0	$0	$0	$0	$0
Aigen	$0	$0	$0	$0	$0	$0	$1,000	$0	$0	$0	$0	$0	$0
Augean Robotics, Inc. (Burro)	$2,500	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Bayer CropScience, LP	$30,000	$0	$0	$0	$0	$0	$30,000	$0	$0	$0	$0	$0	$0
Corteva (Pioneer Hi-Bred International)	$30,000	$0	$0	$0	$0	$0	$30,000	$0	$0	$0	$0	$0	$0
Deere and Co.	$30,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$30,000
FixPosition Ag	$2,500	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$5,000	$0
FMC Corporation	$30,000	$0	$0	$0	$0	$0	$30,000	$0	$0	$0	$0	$0	$0
Headwall Photonics, Inc.	$2,500	$0	$0	$0	$0	$0	$2,500	$0	$0	$0	$0	$0	$0
PureBiomass	$1,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
SoilTech Wireless	$500	$0	$0	$0	$0	$500	$0	$0	$0	$0	$0	$0	$0
SunSouth, LLC	$2,500	$0	$0	$0	$0	$0	$2,500	$0	$0	$0	$0	$0	$0
Syngenta Crop Protection	$30,000	$0	$0	$0	$0	$0	$30,000	$0	$0	$0	$0	$0	$0
Treeswift (Trefos), Inc.	$1,000	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Members	**$163,500**	**$0**	**$0**	**$0**	**$0**	**$1,500**	**$127,000**	**$0**	**$0**	**$0**	**$0**	**$7,500**	**$30,000**
Non-Member Organizations: Funders of Sponsored Projects, Funders of Associated Projects, and Contributing Organizations													
Total Non-Members	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total	**$163,500**	**$0**	**$0**	**$0**	**$0**	**$1,500**	**$127,000**	**$0**	**$0**	**$0**	**$0**	**$7,500**	**$30,000**

ERCWEB TABLE 26: ASSOCIATED PROJECTS

Table: Associated Projects								
Project Name	**Award ID**	**PI Name**	**Funding Source**	**Start Date**	**End Date**	**Total Amount**	**Reporting Year Amount (7/1/2023-6/30/2024)**	**Award Year Amount (9/1/2023-8/31/2024)**
(02AP_AG AID) AI Institute for Transforming Workforce & Decision Support	2AP_AG AID	Reza Ehsani	NSF and USDA-NIFA by the AI Research Institutes program	7/1/2022	6/14/2026	20,000,000	5,065,744	5,065,744
(3AP_HSI AG EDUCATION) Integrated education programs to train students for a future in the agricultural and food industry	3AP_HSI AG EDUCATION	Reza Ehsani	USDA-HSI Hispanic Serving Institutes program	7/1/2022	6/30/2026	999,983	250,509	250,509
(4AP_FUTURE OF WORK) Elevating Farm Worker-Robot Collaborations in Agri-Food Ecosystems	2326310	Stefano Carpin	Other NSF (Not ERC Program)	10/1/2023	9/20/2024	610,609	469,963	576,305
Total						**21,610,592**	**5,786,216**	**5,892,558**

APPENDIX I: GLOSSARY & ACRONYMS

AAB	Aluminum-Air Batteries
ACLAMO	Accion Comunal Latino Americano de Montgomery County (Latin American Action Committee of Montgomery County)
ACRE	Agronomy Center for Research and Education at Purdue University
Ag	Agriculture / Agricultural
Ag/AgCl	Silver Chloride
AG2UG	Above-Ground to Underground
AgAID	Agricultural AI for Transforming Workforce and Decision Support Institute
AgBot	Agricultural autonomous Robot
AI	Artificial Intelligence
AIFS	AI Institute for Food Systems
AIFARMS	Artificial Intelligence for Future Agricultural Resilience, Management, and Sustainability
AIIRA	AI Institute for Resilient Agriculture
ANR	Agriculture and Natural Resources
AOA	Angle of Arrival
AP50	Average Precision (IoU=.50)
API	Application Programming Interface
APSIM	Agricultural Production Systems Simulator
ARM	Advanced RISC Machines
ARS	Agricultural Research Service
ARPA-E	Advanced Research Projects Agency - Energy
ASAB	Agriculture Systems Advisory Board
ASABE	American Society of Agricultural and Biological Engineers
ASEE	American Society for Engineering Education
ASME	American Society of Mechanical Engineers
ASU	Arizona State University
AT	Aflatoxin
AVIRIS	Airborne Visible / Infrared Imaging Spectrometer
AY	Academic Year
BEC	Binary Erasure Channel
BSC	Binary Symmetric Channel

CAN	Controller Area Network
CAST	Council for Agricultural Science and Technology
CBRS	Citizens Broadband Radio Service
CITI	Collaborative Institutional Training Initiative
CMDPs	Constrained Markov Decision Processes
CNF	Cellulose Nanofiber
COCO	Common Objects in Context
COI	Conflict of Interest
CSV	Comma-separated Values
Cu NC	Copper Nanocrystals
CURE-TSR	Challenging Unreal and Real Environments for Traffic Sign Recognition dataset
CWSI	Crop Water Stress Index
DCI	Diversity & Culture of Inclusion
DCIAB	Diversity & Culture of Inclusion Advisory Board
DESIS	DLR Earth Sensing Imaging Spectrometer
DKC	Deaf Kids Code
DOE	Department of Energy
DPM	Dynamic-Power Management
DSSAT	Decision Support System for Agrotechnology Transfer
DXR	Dynamic Extended Resolution
ECE	Electrical and Computer Engineering
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EDGE	Expanding Diversity and Gender Equity
EDI	Equity, Diversity and Inclusion
eDNA	Environmental DNA
EE	Energy Efficiency
EEPROM	Electrically Erasable Programmable Read-Only Memory
EHRS	Environmental Health and Radiation Safety at University of Pennsylvania
ELM	Empirical Line Method
ERC	Engineering Research Center
ESP32	Espressif32
EWD	Engineering Workforce Development
EU	European Union
EVI	Enhanced Vegetation Index

FCOI	Faculty Conflict of Interest related to Research
FDA	U.S. Food and Drug Administration
FDTD	Finite-Difference Time-Domain
FLAASH	Fast Line-of-sight Atmospheric Analysis of Hypercubes
FGLI	First-Generation Low-Income
FOM	Figure of Merit
FY	Fiscal Year
GANS	Genetic Adversarial Networks
GDD	Gaseous Detection Device
GEDI	Global Ecosystem Dynamics Investigation
GERLCA	Geospatial Energy Resources & Life Cycle Assessment Research Group
GHz	Gigahertz
GIS	Geographic Information System
GOES	Geosynchronous Operational Environmental Satellites
GNN	Graph Neural Network
GNDVI	Green Normalized Difference Vegetation Index
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
GRE	Graduate Records Examinations
GT	Ground Terminal
GTRI	Georgia Tech Research Institute
GTSRB	German Traffic Sign Recognition Dataset
HSBCU	Historically Black Colleges and Universities
HIS	Hispanic-Serving Institutions
ICRA	International Conference on Robotics and Automation
IDETC	International Design Engineering Technical Conferences
IE	Innovation Ecosystem
IEEE	Institute of Electrical and Electronics Engineers
IFSM	Integrated Farm System Model
ILO	Industry Liaison Officer
ImageNet	Image Database
IMU	Inertial Measurement Unit
IoT	Internet of Things

IoT4Ag	Internet of Things for Precision Agriculture
IoT4Ag-E^3	IoT4Ag Excite, Educate, Enable (EWD Structure)
IP	Intellectual Property
IPAB	Industrial / Practitioner Advisory Board
IRB	Institutional Review Board
ISAC	Integrated Sensing and Communication
ISAC4Ag	Integrated Sensing and Communication for Agriculture
ISM	Industrial, Scientific, and Medical
IT	Information Technology
ITEX	Intra-ERC Exchange
IUCRC	Industry-University Cooperative Research Centers
JPL	Jet Propulsion Laboratory
JSON	JavaScript Object Notation
KAREC	Kearney Agricultural and Research Extension Center at University of California
kHz	Kilohertz
KSC	Kennedy Space Center
LED	Light-Emitting Diode
LCI	Leaf Chlorophyll Index
LCA	Life Cycle Assessment
LIB	Lithium-ion Batteries
LiDAR	Light Detection and Ranging
LiPO	Lithium-ion Polymer (battery)
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LPAC	Learnable Perception-Action-Communication
LPWAN	Lower Power Wide Area Network
LSTM	Long Short-Term Memory
LSV	Linear Sweep Voltammetry
LTE	Long Term Evolution
MANRRS	Minorities in Agriculture Natural Resources and Related Sciences
MDPs	Markov Decision Processes
MCTS	Monte Carlo Tree Search
MEMS	Micro-Electromechanical Systems
Merced	University of California, Merced

MERCII	Multi-ERC Instrument Inventory
MESH	Modules for Environmental Sensors
MHz	Megahertz
MIL	Multiple Instance Learning
MIMO	Multiple-Input Multiple-Output
MIP	Molecularly Imprinted Polymer
Mo	Molybdenum
MNIST	Modified National Institute of Standards and Technology database
ML	Machine Learning
MSI	Minority Serving Institution
mW	Megawatt
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NC	Nanocrystal
NDRE	Normalized Difference Red Edge Index
NDVI	Normalized Difference Vegetation Index
NFREC	North Florida Research and Education Center at University of Florida
NIP	Non-imprinted Polymer
NIR	Near-Infrared
Nm	Nanometer
NNCI	National Nanotechnology Coordinated Infrastructure
NSF	National Science Foundation
NTN	Non-Terrestrial Network
OADA	Open Ag Data Alliance
OATS	Open Ag Technology and Systems Center at Purdue University
ODROID	Handheld / Mini-PC
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency-Division Multiplexing
OpenCV	Open Computer Vision Library
OSAVI	Optimized Soil Adjusted Vegetation Index
PAC	Perception-Action-Communication
PAWR	Platforms for Advanced Wireless Research
PCB	Printed Circuit Board
Penn	University of Pennsylvania

pH	Potential of Hydrogen
PI	Principal Investigator
POD	Purdue Oats DataStation
PPP	Pathways to Ph.D. Program
PT	Piezoelectric Transformers
Purdue	Purdue University
PVA	Polyvinyl Acetate
Q&A	Questions & Answers
QA/QC	Quality Assurance / Quality Control
QR	Quick Response
QUAC	Quick Atmospheric Correction
R1	Research 1
R2	Research 2
R-CNN	Region Based Convolutional Neural Networks
RANSAC	Random Sample Consensus
REM	Radiological and Environmental Management at Purdue University
REU	Research Experience for Undergraduates
RET	Research Experience for Teachers
RF	Radio-Frequency
RF Chaff	Radio-Frequency countermeasure
RFID	Radio-Frequency Identification
RGB	Red, Green, Blue – color values
RMSE	Root Mean Square Error
ROS2	Robot Operating System 2.0
RS	Remote Sensing
RSJ	Robotics Society of Japan
RTK	Real-Time Kinematic positioning
SAB	Scientific Advisory Board
SACNAS	Society for Advancement of Chicanos/Hispanics and Native Americans in Science
SDK	Software Development Kit
SDR	Software-Defined Radio
SEAS	School of Engineering and Applied Sciences at University of Pennsylvania
SECO	Small-Business/ERC Collaborative Opportunity

SLAM	Simultaneous Localization and Mapping
SLC	Student Leadership Council
SLOAM	Semantic LiDAR Odometry and Mapping
SPLC	Student & Postdoc Leadership Council
SNR	Signal to Noise Ratio
SNRE	School of Natural Resources and Environment
SOFC	Solid Oxide Fuel Cell
SPAD	Single-Photon Avalanche Diode
SRAM	Static Random Access Memory
SSD	Solid-State Drive
STEM	Science, Technology, Engineering, Mathematics
STEP	Stakeholder Engagement Program
SURF	Summer Undergraduate Research Fellowship
SVHN	Street View House Numbers dataset
SVT	Site Visit Team (NSF)
SWAT	Soil and Water Assessment Tool
SWIR	Shortwave Infrared
SWOT	Strengths, Weaknesses, Opportunities, Threats
SWP	Stem Water Potential
SWS	Soil and Water Sciences Department
TIR	Thermal Infrared
TOA	Time of Arrival
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
TRL	Technology Readiness Level
TVWS	Television White Space
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UC	University of California
UGV	Unmanned Ground Vehicle
UF	University of Florida
UHF	Ultrahigh Frequency
UIUC	University of Illinois Urbana-Champaign
URM	Under-Represented Minorities

US	United States
USD	United States Dollar
USB	Universal Serial Bus
USDA	United States Department of Agriculture
VEE	Values-Engaged, Educative (approach)
VIO	Video/Virtual Input/Output
VIS	Visible
ViT	Visual Transformer
VNIR	Visible and Near-Infrared
VPD	Vapor Pressure Deficit
VOC	Volatile Organic Compounds
VOXL	Modular, Open Platform
WFDAB	Workforce Development Advisory Board
WPCN	Wirelessly Powered Communication Network
WPT	Wireless Power Transfer
YOLOv5	You Only Look Once Software
YR	Year
YUV	Luma, Blue Projection, and Red Projection

APPENDIX II. AGREEMENTS AND CERTIFICATIONS

The Agreements and Certifications portion of the Annual Report begins on the next page and contains the following documents:

1. IoT4Ag Core Institution Member Agreement
2. IoT4Ag Industrial/Practitioner Membership Agreement.
3. IoT4Ag Center-wide Intellectual Property Policy
4. A copy of the Human Subjects approval and/or exemptions granted from the relevant Institutional Review Boards (IRBs)
5. Certification of IoT4Ag Industry/Practitioner Membership
6. Certification of IoT4Ag Cumulative and Current Cost Sharing
7. University of Pennsylvania's Conflict-of-Interest Policy and Certification
8. Certification of IoT4Ag Unexpended Residual Funds Table

IoT4Ag Engineering Research Center Core Institution Member Agreement

This IoT4Ag Engineering Research Center Core Institution Member Agreement ("Agreement") is made as of September 21, 2020 ("Effective Date") between **The Trustees of the University of Pennsylvania**, a non-profit, tax-exempt educational institution organized and existing under the laws of the Commonwealth of Pennsylvania, with an address at Penn Center for Innovation, 3600 Civic Center Blvd, 9th Floor, Philadelphia, PA 19104-4310 ("PENN"), on behalf of the Center for the Internet of Things for Agriculture ("the Center"), and the following member institutions: **University of Florida Board of Trustees**, a public body corporate of the state of Florida, having offices at 207 Grinter Hall, Gainesville, FL 32611-5500, **The Regents of the University of California, Merced**, a non-profit, tax-exempt educational institution organized and existing under the laws of the State of California, with an address at 5200 Lake Road, Merced, California 95343, and **Purdue University**, a non-profit, tax-exempt educational institution organized and existing under the laws of the State of Indiana, with an address at 610 Purdue Mall, West Lafayette, IN 47907-2040 (each of which may be referred to herein individually an "Institution Member" or in any combination as "Institution Members"). PENN and the Institution Members form the "Core Institution Members".

WHEREAS, PENN has received funding from the National Science Foundation ("NSF") to act as the "Lead Institution" under the Engineering Research Center ("ERC") program and has joined together with the Institution Members to establish the Center, headquartered at PENN for the purpose of stimulating industrial innovation in the area of precision agriculture; and

WHEREAS, the Center has also sought industry members (each of which may be referred to herein as an "Industry Member" or collectively as the "Industry Members") who have agreed to support the Center and have signed a copy of the IoT4Ag Industry Member Agreement. The Industry Members and the Core Institution Members may each be referred to herein as a "Center Member" or collectively as the "Center Members".

NOW, THEREFORE, the Core Institution Members hereby agree to the following terms and conditions.

1. CENTER ORGANIZATION

1.1 Definitions

a. "Affiliate(s)" as used herein means companies, controlled by, controlling or under common control as a party to the Agreement, with control being defined as direct or indirect ownership of over fifty percent (50% of the outstanding voting securities of an entity).
b. "Center Director" as used herein means Professor Cherie Kagan ("Center Director"), a faculty member at PENN.
c. "Core Research" as used herein means research that the Executive Committee (as defined below) determines shall be: (a) conducted through the Center by faculty, students and staff from Core Institution Members, and (b) financially supported by funds from NSF ERC program, Core Institution Members *via* cost sharing, and from Membership Fees.
d. "Executive Committee" as used herein refers to the leadership of the Center, led by the Center Director (as defined below) and compromised of representatives from each of the Core Institution Members. The Executive Committee is responsible for management and administration of the Center under the direction of the Center Director, including addressing issues concerning the effectiveness of the Center and selecting, overseeing, and managing the Core Research to be conducted by the Center.

e. "IPAB" as used herein means the Industry and Practitioners Advisory Board. Every Industry Member can select a representative to serve on the IPAB. The IPAB is responsible for advising the Executive Committee on the direction of Core Research and the operational policies of the Center. The Executive Committee and the IPAB shall meet at least biannually. A quorum of the IPAB shall consist of a simple majority of the Industry Members. In all matters before the IPAB, a simple majority is needed for any vote to pass. The meeting logistics and other operating procedures of the IPAB are outside of this Agreement and will be determined separately by the IPAB.

f. "Research Results" as used herein means all data and information which are generated by or on behalf of a Core Institution Member in the performance of the Core Research during the term of this Agreement. Research Results expressly excludes Intellectual Property.

g. "Intellectual Property" as used herein means all inventions, whether patentable or not, conceived and first reduced to practice (as determined by United States patent law) by or on behalf of a Core Institution Member in the conduct of the Core Research, including all United States and foreign patent applications claiming said patentable inventions, including any divisional, continuation, continuation-in-part (to the extent that the claims are directed to said patentable inventions), and foreign equivalents thereof, as well as any patents issued thereon or reissues or reexaminations thereof. Intellectual Property also includes all significant copyrights and copyrightable software authored (as determined by United States copyright law) by a Core Institution Member in the conduct of the Core Research.

1.2 Center activities were funded by the NSF ERC program on September 1, 2020. The Center is managed and administered under the direction of the Center Director and supported jointly by Institution Members, Industry Members, and by PENN personnel selected by the Center Director from PENN faculty and staff. At the discretion of the Center Director, additional personnel from Institution Members and Industry Members may be added at any time to assist in management and administration of the Center; provided that any such personnel who will be temporarily in residence at PENN as researchers for the Center will be considered Visiting Scholars and may be asked to sign a separate Visiting Scholars Agreement before such residency shall begin.

1.3 Each Industry Member will provide payment of its annual membership fees in accordance with its Industry Member Agreement ("Membership Fees"). Core Research supported by Industry Membership Fees is not subject to facilities and administrative costs. Membership in the Center does not preclude any Core Institution Member from entering into separate research agreements with Industry Members who participate in the Center.

2. RESEARCH RESULTS; REPORTS

2.1 Core Institution Members engaged in Core Research shall provide the Executive Committee and the IPAB with interim reports detailing preliminary Research Results and the status and progress of the Core Research as requested by the Executive Committee. Core Institution Members engaged in Core Research shall also provide the Executive Committee and the IPAB a final report summarizing the Research Results at the conclusion of a Core Research project. The interim reports and final reports shall together be referred to herein as "Reports".

2.2 Center Members shall have the right to use Research Results disclosed to them in Reports for any lawful purpose, and are hereby granted a royalty-free, nontransferable, non-exclusive right

to copy, reproduce and distribute said Reports, provided that: (a) a Center Member shall need to obtain a license to use Research Results from the Center Member(s) who generated such Research Results if such use would infringe any copyright or any claim of a patent application or issued patent owned by the Center Member(s) that authored the Report; (b) Center Members shall maintain the Research Results confidentially pending publication in accordance with Section 4.6; (c) Center Members may not charge fees for said research reports, use said research reports for advertising or promotional activities, or alter or modify said research reports without the prior written permission of the Center Member(s) who authored the Report.

3. INTELLECTUAL PROPERTY

3.1 Ownership of Intellectual Property shall follow inventorship in accordance with United States patent law or authorship in accordance with United States copyright law, as applicable.

3.2 The owner(s) of Intellectual Property in accordance with Section 3.1 hereby grant the other Center Members a non-exclusive, royalty-free, non-transferable, non-sublicensable license to practice such Intellectual Property for only non-commercial, internal research use (hereinafter an "Internal Use License"), provided that (a) such Intellectual Property was conceived and first reduced to practice, or first authored, during the Center Member's membership in the Center; and (b) with respect to Industry Members, the Industry Member has paid its annual Membership Fee.

3.3 With respect to potentially patentable Intellectual Property, Core Institution Members shall provide the IPAB with prompt written notice of any Intellectual Property reasonably considered patentable and, in the case of software or data collections, is reasonably considered to be technologically valuable ("IP Disclosure").

a. The IPAB will have thirty (30) days following receipt of an IP Disclosure ("Review Period") to make a recommendation with respect to the filing and prosecution of a patent application claiming such Intellectual Property.
b. If the IPAB makes a recommendation during the Review Period in support of filing and prosecution of a patent application claiming the disclosed Intellectual Property, the owner of the Intellectual Property shall control the preparation and prosecution of such patent application and the costs associated with preparation and filing fees (U.S. only) will be reimbursed by the Center from Industry Membership Fees, provided sufficient funds are available. In the event sufficient funds are not available the costs associated with preparation and filing fees will be borne equally by the Industry Members voting in favor of filing and prosecution of a patent application.
c. If the IPAB does not respond within the Review Period or makes a recommendation during the Review Period against filing and prosecution of a patent application claiming the disclosed Intellectual Property, the owner of the Intellectual Property may decide independently to proceed with patent filing and prosecution at its own expense and such Intellectual Property shall not be subject to the Option as described below.

3.4 Industry Members shall have sixty (60) days from receipt of an IP Disclosure ("Option Period") to elect to exercise an option to negotiate a royalty-bearing non-exclusive license to practice the Intellectual Property described in such IP Disclosure for commercial purposes ("Option").

3.5 Any Industry Members who exercise their Option during the Option Period will negotiate with the owner of the Intellectual Property in good faith to determine the terms of a license agreement. If a license agreement is not executed within six (6) months after the Industry Member's election of the Option, the owner of the Intellectual Property shall be free to license Intellectual Property to any Center Member, or to any non-member small business or start-up upon such terms as it deems appropriate, without any further obligation to the Industry Member(s). If, at the conclusion of the Option Period, only one Industry Member seeks a license, that Industry Member may negotiate to obtain from the Owner of the Intellectual Property a royalty-bearing license that is exclusive, except that the license is subject to the rights of the federal government under the Bayh-Dole Act.

3.6 Center Members' respective rights under this Article 3 shall be subject to the Center's and the Core Institution Members' obligations to and the rights of the United States Government, if any, as subject to the provisions of 35 U.S.C. 200, et seq., 37 C.F.R. Part 401, and other applicable laws and regulations.

4. CONFIDENTIALITY AND PUBLICATION

4.1 From time to time Center Members may have the need to exchange Confidential Information in connection with the performance of Core Research. The Core Institution Members shall be a "Disclosing Party" and/or a "Receiving Party" of Confidential Information as context dictates. The Industry Members shall be a "Receiving Party" only. "Confidential Information" means any of a Core Institution Member's confidential or proprietary information- that is necessary to be disclosed to another Center Member in connection with performance of the Core Research and is marked "confidential" or "proprietary" or, if disclosed orally, is summarized in writing sufficiently for identification and is designated in writing as confidential within thirty (30) days following disclosure. Failure to mark any Confidential Information as confidential or proprietary will not affect its status as Confidential Information under this Agreement if it is information that a reasonable person with expertise in the field would consider the Disclosing Party's Confidential Information hereunder based upon the nature of the information and the circumstances of the disclosure. Confidential Information shall not include information:

a. that is or becomes generally known or available to the public without breach of this Agreement;
b. that is known to the Receiving Party at the time of disclosure, as evidenced by written records of the Receiving Party;
c. that is independently developed by the Receiving Party, as evidenced by written records of the Receiving Party; or
d. that is disclosed to the Receiving Party by a third party without an obligation of confidentiality owed by Receiving Party to such third party; or
e. that is required to be disclosed by law, in which case Receiving Party shall promptly inform the Disclosing Party and shall cooperate with the Disclosing Party to minimize the extent of the disclosure.

4.2 Receiving Party will be permitted to make all disclosures of Disclosing Party's Confidential Information required by law or regulation. Receiving Party shall use reasonable efforts to provide prompt written notice to Disclosing Party to allow Disclosing Party to offer its

objections to the production of Confidential Information. The Confidential Information that is disclosed pursuant to this paragraph shall remain confidential for all other purposes in accordance with the terms and conditions of this Agreement.

4.3 Receiving Party will take all reasonable measures to protect the secrecy of, and avoid the unauthorized disclosure or use of, Confidential Information. Such measures will include the highest degree of care that Receiving Party utilizes to protect Receiving Party's own confidential information of a similar nature, but no less than a reasonable degree of care. Receiving Party will not use Confidential Information for any purpose, other than as necessary to carry out the Core Research. Specifically, Receiving Party will not use Confidential Information to file patent applications or for experimental activity. No licenses or other rights are granted. Receiving Party may disclose Confidential Information to Affiliates, employees, agents or consultants on a need to know basis if such persons are bound to obligations of non-use or non-disclosure at least as restrictive as those set forth in this Agreement. Recipient will not disclose any Confidential Information to any other Affiliates, employees, agents, consultants, or to any third parties. Receiving Party will promptly notify Disclosing Party in writing of any misuse or misappropriation of any Confidential Information that may come to Receiving Party's attention. Receiving Party will be responsible for any breach of this Agreement by its Affiliates, employees, agents, or consultants.

4.4 Disclosing Party represents that it has the right to make the disclosures of Confidential Information made hereunder. Except as expressly set forth in this Section 4.4, Disclosing Party is providing Confidential Information on an "*As Is*" basis for use by Receiving Party at its own risk without express or implied warranties of any kind.

4.5 Receiving Party's obligations as to any item of Confidential Information will survive during the term of this Agreement and shall continue for five (5) years following the expiration or termination of this Agreement. Upon the written request of Disclosing Party, Receiving Party will destroy or return to Disclosing Party all Confidential Information received from Disclosing Party, except that Receiving Party may maintain a single copy of any written Confidential Information for Receiving Party's records. Notwithstanding the foregoing, the obligation to return or destroy Confidential Information does not include Confidential Information that has been backed up as part of the Receiving Party's normal business procedures, and the Receiving Party may reproduce Confidential Information in the process of backing up computer systems in the normal course of business.

4.6 The Core Institution Members shall have the first right to publish, present or otherwise publicly disclose the Research Results developed under this Agreement ("Publish"). Any Core Institution Member wishing to Publish shall furnish the Executive Committee and IPAB with a copy of the proposed publication, presentation, or other public disclosure (each a "Publication") at least thirty (30) days in advance of the date of such presentation or disclosure, or the submission of said proposed publication, in order for the Executive Committee and IPAB to review and comment on said proposed Publication to (a) determine whether such Publication contains any Confidential Information of any of the other Core Institution Members; and (b) enable the Industry Members to identify any Intellectual Property for which it wishes to seek intellectual property protection. If within the thirty (30) day review period (i) a Core Institution Member requests deletion of Confidential Information from the proposed Publication, the Core Institution Members at issue will cooperate to modify the disclosure to ensure Confidential Information is not disclosed; or (ii) an Industry Member requests that the Proposed publication

be delayed to allow for intellectual property protection on certain items of Intellectual Property in the proposed Publication, the publishing Core Institution Member shall delay the proposed Publication for up to sixty (60) days to allow for intellectual property protection to be sought.

5. DISCLAIMER OF WARRANTIES; INDEMNIFICATION

5.1 NO CORE INSTITUTION MEMBER MAKES ANY WARRANTIES, EXPRESS OR IMPLIED, AS TO ANY MATTER WHATSOEVER, INCLUDING, WITHOUT LIMITATION, WARRANTIES WITH RESPECT TO THE CONDUCT, COMPLETION, SUCCESS OR PARTICULAR RESULTS OF THE CORE RESEARCH, OR THE CONDITION, OWNERSHIP, MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE OF THE CORE RESEARCH OR ANY INTELLECTUAL PROPERTY OR RESEARCH RESULTS, OR THAT USE OF INTELLECTUAL PROPERTY OR RESEARCH RESULTS WILL NOT INFRINGE ANY PATENT, COPYRIGHT, TRADEMARK OR OTHER INTELLECTUAL PROPERTY RIGHT OF A THIRD PARTY. EXCEPT AS SET FORTH IN SECTION 5.2 NO CORE INSTITUTION MEMBER SHALL BE LIABLE FOR ANY DIRECT, INDIRECT, CONSEQUENTIAL, PUNITIVE OR OTHER DAMAGES SUFFERED BY ANOTHER CORE INSTITUTION MEMBER RESULTING FROM THE CORE RESEARCH OR THE USE OF ANY INTELLECTUAL PROPERTY, ANY RESEARCH RESULTS OR ANY PRODUCTS RESULTING THEREFROM.

5.2 To the extent permitted under state and federal statutes, constitutional provisions and other law, each party shall be responsible for its own negligent acts or omissions and the negligent acts or omissions of its officers, directors, trustees, employees and agents that arise out of or are related to the performance of the obligations under this Agreement This provision is intended to be an allocation of risk between the parties, and shall not constitute an indemnification.

6. MISCELLANEOUS

6.1 No Center Member shall use the name, logo, seal, trademark, or service mark (including any adaptation of them) of any other Center Member, including any school, organization, employee, student or representative thereof, without the prior written consent of that Center Member. No Center Member except PENN shall use the name of the Center without the prior written consent of PENN. Notwithstanding the foregoing, Center Members may use the name of the Center in a non-misleading, factual manner to state Center Members' participation in the ERC without PENN's consent.

6.2 For purposes of this Agreement and membership in the Center, the Center Members shall be independent contractors and none shall at any time be considered an agent or an employee of the other. No joint venture, partnership or like relationship is created between any of the Center Members by their membership in the Center or this Agreement.

6.3 The terms and provisions hereof shall inure to the benefit of, and be binding upon, the Center Members and their respective successors and permitted assigns. No Center Member may assign or transfer this Agreement or any of its rights or obligations created hereunder, by operation of law or otherwise, without the prior written consent of the other Parties. Any assignment not in accordance with this Section 6.3 shall be void. However, transferring a Center Member's licensing and intellectual property obligations to their respective office of

technology commercialization, office of tech transfer or other similar Center Member office, shall not be a breach of this provision.

6.4 A waiver by a Center Member of any of the terms and conditions of this Agreement in any instance shall not be deemed or construed to be a waiver of such term or condition for the future, or of any other term or condition hereof. All rights, remedies, undertakings, obligations and agreements contained in this Agreement shall be cumulative and none of them shall be in limitation of any other remedy, right, undertaking, obligation or agreement of a Center Member.

6.5 When possible, each provision of this Agreement will be interpreted in such manner as to be effective and valid under law, but if any provision of this Agreement is held to be prohibited by or invalid under law, such provision will be ineffective only to the extent of such prohibition or invalidity, without invalidating the remainder of this Agreement. The Center Members shall make a good faith effort to replace the invalid or unenforceable provision with a valid one which in its economic effect is most consistent with the invalid or unenforceable provision.

6.6 This Agreement constitutes the entire agreement between the Core Institution Members with respect to its subject matter, and supersedes all previous communications and agreements, whether oral or written, between the Core Institution with respect to the subject matter hereof. This Agreement may be waived, modified, or amended only by an instrument in writing and signed by duly authorized representatives of all Core Institution Members.

6.7 This Agreement may be executed in counterparts, each of which will be deemed an original, and all of which together will be deemed to be one and the same instrument. A portable document format (PDF) or electronic copy of this Agreement, including the signature pages, will be deemed an original.

[SIGNATURE PAGE FOLLOWS]

IN WITNESS WHEREOF, the duly authorized representatives of the Parties hereby execute this Agreement as of the date first written above.

THE TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA

By: _____

Name: Jacqueline Rodriguez

Title: Associate Director, Corporate Contracts

PURDUE UNIVERSITY

By: _____

Daniel J. Reed | Lead Analyst
PURDUE UNIVERSITY
SPONSORED PROGRAM SERVICES CONTRACTING

Digitally signed by Daniel J. Reed
Date: 2020.10.14 16:06:33 -04'00'

Name: _____

Title: _____

UNIVERSITY OF FLORIDA BOARD OF TRUSTEES

By: _____

Name: _____

Title: _____

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA,MERCED

By: _____

Name: _____

Title: _____

ACKNOWLEDGED AS READ AND UNDERSTOOD BY CENTER DIRECTOR AND LEAD PRINCIPAL INVESTIGATORS:

By: _____

Name: Cherie Kagan

Center Director, University of Pennsylvania

By: _____

David Arnold

Lead Principal Investigator, University of Florida

By: _____

Name: David Cappelleri

Lead Principal Investigator, Purdue University

By: _____

Catherine Keske

Lead Principal Investigator, University of California, Merced

IN WITNESS WHEREOF, the duly authorized representatives of the Parties hereby execute this Agreement as of the date first written above.

THE TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA

By: _____

Name: _____

Title: _____

PURDUE UNIVERSITY

By: _____

Name: _____

Titl
e: _____

UNIVERSITY OF FLORIDA BOARD OF TRUSTEES

By: Lisa C Stroud Digitally signed by Lisa C Stroud Date: 2020.10.20 08:41:44 -04'00'

Name: Lisa C Stroud

Title: Associate Director

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA,MERCED

By: _____

Name: _____

Titl
e: _____

ACKNOWLEDGED AS READ AND UNDERSTOOD BY CENTER DIRECTOR AND LEAD PRINCIPAL INVESTIGATORS:

By: _____

Name: Cherie Kagan

Center Director, University of Pennsylvania

By: _____

Name: David Cappelleri

Lead Principal Investigator, Purdue University

By: _____

David Arnold
Lead Principal Investigator, University of Florida

By: _____

Catherine Keske
Lead Principal Investigator, University of California, Merced

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By: _____

Name: _____

Title: _____

PURDUE UNIVERSITY

By: _____

Name: _____

Title: _____

UNIVERSITY OF FLORIDA BOARD OF TRUSTEES

By: _____

Name: Lisa C Stroud

Title: Associate Director

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA,MERCED

By: _____

Name: _____

Title: _____

ACKNOWLEDGED AS READ AND UNDERSTOOD BY CENTER DIRECTOR AND LEAD PRINCIPAL INVESTIGATORS:

By: _____

Name: Cherie Kagan

Center Director, University of Pennsylvania

By: _____

David Arnold

Lead Principal Investigator, University of Florida

By: _____

Name: David Cappelleri

Lead Principal Investigator, Purdue University

By: _____

Catherine Keske

Lead Principal Investigator, University of California, Merced

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THE TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA

By: _____

Name: _____

Title: _____

PURDUE UNIVERSITY

By: _____

Name: _____

Title: _____

UNIVERSITY OF FLORIDA BOARD OF TRUSTEES

By: _____

Name: _____

Title: _____

THE REGENTS OF THE UNIVERSITY OF CALIFORNIA,MERCED

By: _____

Name: _____

Title: _____

ACKNOWLEDGED AS READ AND UNDERSTOOD BY CENTER DIRECTOR AND LEAD PRINCIPAL INVESTIGATORS:

By: _____

Name: Cherie Kagan

Center Director, University of Pennsylvania

By: _____

Name: David Cappelleri

Lead Principal Investigator, Purdue University

By: _____

David Arnold
Lead Principal Investigator, University of Florida

By: _____

Catherine Keske
Lead Principal Investigator, University of California, Merced

IoT4Ag Engineering Research Center Industry Member Agreement

This IoT4Ag Engineering Research Center Industry Member Agreement ("Agreement") is made as of _____ ("Effective Date") between The University of Pennsylvania, a non-profit, tax-exempt educational institution organized and existing under the laws of the Commonwealth of Pennsylvania, with an address at Penn Center for Innovation, 3600 Civic Center Blvd, 9th Floor, Philadelphia, PA 19104-4310 ("PENN"), on behalf of the Center for the Internet of Things for Agriculture ("the Center"), and _____ a _____ organized and existing under the laws of _____, with an address at _____ _____ (referred to herein as an "_____").

WHEREAS, PENN has received funding from the National Science Foundation ("NSF") to act as the "Lead Institution" under the Engineering Research Center ("ERC") program and has joined together with the University of Florida, University of California – MERCED, and Purdue University (each of which may be referred to herein individually an "Institution Member" or in any combination as "Institution Members", PENN and the Institution Members collectively being the "Core Institution Members") to establish the Center, headquartered at PENN for the purpose of stimulating industrial innovation in the area of precision agriculture; and

WHEREAS, the Center has also sought industry members such as _____ to support the Center (each of which may be referred to herein as an "Industry Member" or collectively as the "Industry Members"). The Industry Members and the Core Institution Members may each be referred to herein as a "Center Member" or collectively as the "Center Members"

NOW, THEREFORE, PENN and _____ ("Party" or "Parties") hereby agree to the following terms and conditions.

This Agreement shall be valid for an annual term beginning on the Effective Date and may be renewed on an annual basis by continued payment of the annual membership fee (the first such annual term following the Effective Date set forth above is referred to herein as the "Initial Term").

1. CENTER ORGANIZATION

1.1 Definitions

a. "Affiliate(s)" as used herein means companies, controlled by, controlling or under common control as a party to the Agreement, with control being defined as direct or indirect ownership of over fifty percent (50% of the outstanding voting securities of an entity).

b. “Center Director” as used herein means Professor Cherie Kagan (“Center Director”), a faculty member at PENN.
c. “Life of the Center” as used herein means from the Effective Date until the expiration or termination of the NSF award for the Center.
d. “Core Research” as used herein means research that the Executive Committee (as defined below) determines shall be: (a) conducted through the Center by faculty, students and staff from Core Institution Members, and (b) financially supported by funds from NSF ERC program, Core Institution Members *via* cost sharing, and from Membership Fees.
e. “Executive Committee” as used herein refers to the leadership of the Center, led by the Center Director (as defined below) and compromised of representatives from each of the Core Institution Members. The Executive Committee is responsible for management and administration of the Center under the direction of the Center Director, including addressing issues concerning the effectiveness of the Center and selecting, overseeing, and managing the Core Research to be conducted by the Center.
f. “IPAB” as used herein means the Industry and Practitioners Advisory Board. Every Industry Member can select a representative to serve on the IPAB. The IPAB is responsible for advising the Executive Committee on the direction of Core Research and the operational policies of the Center. The IPAB shall communicate with the Executive Committee via an Industrial and Practitioner Executive Committee (“IPEC”) consisting of 10 members elected by the IPAB. The Executive Committee and the IPEC shall meet at least biannually. A quorum of the IPAB shall consist of a simple majority of the Industry Members. In all matters before the IPAB, each Industry Member shall be entitled to the number of votes indicated in the table of section 1.4 below and a simple majority is needed for any vote to pass. The meeting logistics and other operating procedures of the IPAB and IPEC are outside of this Agreement and will be determined separately by the IPAB.
g. “Research Results” as used herein means all data and information which are generated by or on behalf of a Core Institution Member in the performance of the Core Research during the term of this Agreement. Research Results expressly excludes Intellectual Property.
h. “Intellectual Property” as used herein means all inventions, whether patentable or not, conceived and first reduced to practice (as determined by United States patent law) by or on behalf of a Core Institution Member in the conduct of the Core Research, including all United States and foreign patent applications claiming said patentable inventions, including any divisional, continuation, continuation-in-part (to the extent that the claims are directed to said patentable inventions), and foreign equivalents thereof, as well as any patents issued thereon or reissues or reexaminations thereof. Intellectual Property also includes all significant copyrights and copyrightable software authored (as determined by United States copyright law) by a Core Institution Member in the conduct of the Core Research.

1.2 Center activities were funded by the NSF ERC program on September 1, 2020. The Center is managed and administered under the direction of the Center Director and supported jointly by Institution Members, Industry Members, and by PENN personnel selected by the Center Director from PENN faculty and staff. At the discretion of the Center Director, additional personnel from Institution Members and Industry Members may be added at any time to assist in management and administration of the Center;

provided that any such personnel who will be temporarily in residence at PENN as researchers for the Center will be considered Visiting Scholars and may be asked to sign a separate Visiting Scholars Agreement before such residency shall begin.

1.3 Core Research supported by Membership Fees (as defined below) is not subject to facilities and administrative costs. Membership in the Center does not preclude any Industry Member from entering into separate research agreements with Core Industry Members who participate in the Center.

1.4 Each Industry Member (excluding Non-Commercial Entities, as defined below) that comprises a company, corporation, partnership, sole proprietorship, or any other legally recognized business entity (each a "Commercial Entity") will provide payment of its annual membership
fee ("Membership Fee") and shall be entitled to a corresponding number of votes on the IPAB in accordance with the following Membership Fee schedule:

Type of Entity	No. of Employees	Annual Contribution	IPAB Votes
Large Entities	≥500	$30,000	3
Medium Entities	100-499	$15,000	2
Small Entities	11-99	$2,500	1
Very Small Entities	≤10	$1,000	1

Governmental agencies, government offices, government organizations duly authorized by the United States Government or government of any State or Nation, and legally recognized nonprofit organizations other than the Core Institution Members who are not representatives or affiliates of any for-profit entities (each a "Non-Commercial Entity") may also become an Industry Member, but such Non-Commercial Entities will not be required to pay a Membership Fee, shall not be entitled to any votes on the IPAB, and shall not receive the Intellectual Property license rights or Option set forth in Article 3 below.

_____ entity type (Commercial/size or Non-Commercial) is indicated here:

_____

_____

1.5 An organization that qualifies as a Non-Commercial Entity but voluntarily wishes to join as a dues-paying Commercial Entity may do so with the Center Director's prior written consent and will be deemed a Commercial Entity for purposes of this Agreement.

1.6 A Commercial Entity who voluntarily wishes to join and pay dues at a higher tier than required for its size, in order to obtain the larger number of IPAB votes

corresponding to that tier in the table of 1.4, may do so with the Center Director's prior written consent.

1.7 The Center Director shall have discretion to make exceptions to Section 1.4 whereby a Commercial Entity may provide a portion of its payment of its annual Membership Fee to IoT4Ag in the form of in-kind contributions; provided that such contributions shall be limited to tangible contributions (i.e. material, capital equipment, etc.).

1.8 Payment of the Membership Fee shall be made within thirty (30) days after the execution of this Agreement and receipt of an invoice from PENN. Payments shall be made in United States dollars and sent to the address noted on the invoice. Industry Members cannot direct use of the Membership Fees.

1.9 Following expiration of the Initial Term, and for the remaining Life of the Center, a Commercial Entity may elect to renew its participation as an Industry Member under this Agreement, on a yearly basis, by making payment(s) of subsequent annual Membership Fee(s) within thirty (30) days of receipt of an invoice from PENN showing the annual Membership Fee applicable for the following annual term. A Commercial Entity's status as an Industry Member shall expire at the conclusion of the Initial Term (or of a renewal term) if renewal payment is not made in accordance with this Section 1.9.

1.10 Industry Member may terminate the Agreement by giving ninety (90) days written notice of such termination. The Center Director may terminate this Agreement, and the Industry Member's status as a Center Member, if the Industry Member materially breaches any of the terms or conditions of this Agreement and fails to cure such breach within thirty (30) days after receiving written notice thereof. In the event of an incurable material breach, the Center Director may terminate this Agreement, and the Industry Member's status as a Center Member, effective immediately upon written notice to the Industry Member. Membership Fees paid prior to the effective date of early termination of this Agreement by either Party will not be refunded.

2. RESEARCH RESULTS; REPORTS

2.1 Core Institution Members engaged in Core Research shall provide the Executive Committee and the IPAB with interim reports detailing preliminary Research Results and the status and progress of the Core Research as requested by the Executive Committee. Core Institution Members engaged in Core Research shall also provide the Executive Committee and the IPAB a final report detailing the complete Research Results at the conclusion of a Core Research project. The interim reports and final reports shall together be referred to herein as "Reports".

2.2 Center Members shall have the right to use Research Results disclosed to them in Reports for any lawful purpose, and are hereby granted a royalty-free, nontransferable,

non-exclusive right to copy, reproduce and distribute said Reports, provided that: (a) a Center Member shall need to obtain a license to use Research Results from the Center Member(s) who generated such Research Results if such use would infringe any copyright or any claim of a patent application or issued patent owned by the Center Member(s) that authored the Report; (b) Center Members shall maintain the Research Results confidentially pending publication in accordance with Section 4.6; (c) Center Members may not charge fees for said research reports, use said research reports for advertising or promotional activities, or alter or modify said research reports without the prior written permission of the Center Member(s) who authored the Report.

3. INTELLECTUAL PROPERTY

3.1 Ownership of Intellectual Property shall follow inventorship in accordance with United States patent law or authorship in accordance with United States copyright law, as applicable.

3.2 The owner(s) of Intellectual Property in accordance with Section 3.1 hereby grant the other Center Members (excluding Non-Commercial Entities) a non-exclusive, royalty-free, nontransferable, non-sublicensable license to practice such Intellectual Property for only noncommercial, internal research use for the Life of the Center (hereinafter an "Internal Use License"), provided that (a) such Intellectual Property was conceived and first reduced to practice, or first authored, during the Center Member's membership in the Center; (b) with respect to Industry Members, the Industry Member has paid its annual Membership Fee; and (c) Center Member acknowledges the Center and the NSF Engineering Research Center (ERC) program in any publication based on use of this license.

3.3 Core Institution Members shall provide the IPAB with prompt written notice of any Intellectual Property reasonably considered patentable or, in the case of Intellectual Property consisting of software or data collections, is reasonably considered to be technologically valuable ("IP Disclosure").

a. The IPAB will have thirty (30) days following receipt of an IP Disclosure ("Review Period") to make a recommendation with respect to the filing and prosecution of a patent application claiming such Intellectual Property.
b. If the IPAB makes a recommendation during the Review Period in support of filing and prosecution of a patent application claiming the disclosed Intellectual Property, the owner of the Intellectual Property shall control the preparation and prosecution of such patent application and the costs associated with preparation and filing fees (initial U.S. application only) will be reimbursed by the Center from Industry Membership Fees, provided sufficient funds are available. In the event sufficient funds are not available the costs associated with such preparation and filing fees will be borne equally by the Industry Members voting in favor of filing and prosecution of a patent application.
c. If the IPAB does not respond within the Review Period or makes a recommendation during the Review Period against filing and prosecution of a patent application claiming the disclosed Intellectual Property, the owner of the Intellectual Property may decide independently to proceed with patent filing and

prosecution at its own expense and may offer an option to Industry Members according to the terms outlined below.

3.4 Industry Members (excluding Non-Commercial Entities) shall have sixty (60) days from receipt of an IP Disclosure ("Option Period") to elect to exercise an option to negotiate a royalty-bearing non-exclusive license to practice the Intellectual Property for commercial purposes ("Option"). The Option is non-transferable and is personal to the Commercial Entity that is an Industry Member.

3.5 Any Industry Members (excluding Non-Commercial Entities) who exercise their Option during the Option Period will negotiate with the owner of the Intellectual Property in good faith to determine the terms of a license agreement. If a license agreement is not executed within six (6) months after the Industry Member's election of the Option, the owner of the Intellectual Property shall be free to license Intellectual Property to any Center Member, or to any nonmember small business or start-up, upon such terms as it deems appropriate, without any further obligation to the Industry Member(s).

3.6 Center Members' respective rights under this Article 3 shall be subject to the Center's and the Core Institution Members' obligations to and the rights of the United States Government, if any, as subject to the provisions of 35 U.S.C. 200, et seq., 37 C.F.R. Part 401, and other applicable laws and regulations.

4. CONFIDENTIALITY AND PUBLICATION

4.1 From time to time Center Members may have the need to exchange Confidential Information in connection with the performance of Core Research. The Core Institution Members shall be a "Disclosing Party" and/or a "Receiving Party" of Confidential Information as context dictates. The Industry Members shall be a "Receiving Party" only. "Confidential Information" means any of a Core Institution Member's confidential or proprietary information that is necessary to be disclosed to another Center Member in connection with performance of the Core Research and is marked "confidential" or "proprietary" or, if disclosed orally, is summarized in writing sufficiently for identification and is designated in writing as confidential within thirty (30) days following disclosure. Failure to mark any Confidential Information as confidential or proprietary will not affect its status as Confidential Information under this Agreement if it is information that a reasonable person with expertise in the field would consider the Disclosing Party's Confidential Information hereunder based upon the nature of the information and the circumstances of the disclosure. Confidential Information shall not include information:

a. that is or becomes generally known or available to the public without breach of this
Agreement;
b. that is known to the Receiving Party at the time of disclosure, as evidenced by written records of the Receiving Party;
c. that is independently developed by the Receiving Party, as evidenced by written records of the Receiving Party; or
d. that is disclosed to the Receiving Party by a third party without an obligation of confidentiality owed by Receiving Party to such third party; or

e. that is required to be disclosed by law, in which case Receiving Party shall promptly inform the Disclosing Party and shall cooperate with the Disclosing Party to minimize the extent of the disclosure.

4.2 Receiving Party will be permitted to make all disclosures of Disclosing Party's Confidential Information required by law or regulation. Receiving Party shall use reasonable efforts to provide prompt written notice to Disclosing Party to allow Disclosing Party to offer its objections to the production of Confidential Information. The Confidential Information that is disclosed pursuant to this paragraph shall remain confidential for all other purposes in accordance with the terms and conditions of this Agreement.

4.3 Receiving Party will take all reasonable measures to protect the secrecy of, and avoid the unauthorized disclosure or use of, Confidential Information. Such measures will include the highest degree of care that Receiving Party utilizes to protect Receiving Party's own confidential information of a similar nature, but no less than a reasonable degree of care. Receiving Party will not use Confidential Information for any purpose, other than as necessary to carry out the Core Research. Specifically, Receiving Party will not use Confidential Information to file patent applications or for experimental activity. No licenses or other rights are granted. Receiving Party may disclose Confidential Information to Affiliates, employees, agents or consultants on a need to know basis only if such persons are bound to obligations of non-use or non-disclosure at least as restrictive as those set forth in this Agreement. Recipient will not disclose any Confidential Information to any other Affiliates, employees, agents, consultants, or to any third parties. Receiving Party will promptly notify Disclosing Party in writing of any misuse or misappropriation of any Confidential Information that may come to Receiving Party's attention. Receiving Party will be responsible for any breach of this Agreement by its Affiliates, employees, agents, or consultants.

4.4 Disclosing Party represents that it has the right to make the disclosures of Confidential Information made hereunder. Except as expressly set forth in this Section 4.4, Disclosing Party is providing Confidential Information on an "*As Is*" basis for use by Receiving Party at its own risk without express or implied warranties of any kind.

4.5 Receiving Party's obligations as to any item of Confidential Information will survive during the term of this Agreement and shall continue for five (5) years following the expiration or termination of this Agreement. Upon the written request of Disclosing Party, Receiving Party will destroy or return to Disclosing Party all Confidential Information received from Disclosing Party, except that Receiving Party may maintain a single copy of any written Confidential Information for Receiving Party's records. Notwithstanding the foregoing, the obligation to return or destroy Confidential Information does not include Confidential Information that has been backed up as part of the Receiving Party's normal business procedures, and the Receiving Party may reproduce Confidential Information in the process of backing up computer systems in the normal course of business.

4.6 The Core Institution Members shall have the first right to publish, present or otherwise publicly disclose the Research Results developed under this Agreement ("Publish"). Any Core Institution Member wishing to Publish shall furnish the Executive Committee

and IPAB with a copy of the proposed publication, presentation, or other public disclosure (each a "Publication") at least thirty (30) days in advance of the date of such presentation or disclosure, or the submission of said proposed publication, in order for the Executive Committee and IPAB to review and comment on said proposed Publication to (a) determine whether such Publication contains any Confidential Information of any of the other Core Institution Members; and (b) enable the Industry Members to identify any Intellectual Property for which it wishes to seek intellectual property protection. If within the thirty (30) day review period (i) a Core Institution Member requests deletion of Confidential Information from the proposed Publication, the Core Institution Members at issue will cooperate to modify the disclosure to ensure Confidential Information is not disclosed; or (ii) an Industry Member requests that the Proposed publication be delayed to allow for intellectual property protection on certain items of Intellectual Property in the proposed Publication, the publishing Core Institution Member shall delay the proposed Publication for up to sixty (60) days to allow for intellectual property protection to be sought.

5. DISCLAIMER OF WARRANTIES; INDEMNIFICATION

5.1 NO CORE INSTITUTION MEMBER MAKES ANY WARRANTIES, EXPRESS OR IMPLIED, AS TO ANY MATTER WHATSOEVER, INCLUDING, WITHOUT LIMITATION, WARRANTIES WITH RESPECT TO THE CONDUCT, COMPLETION, SUCCESS OR PARTICULAR RESULTS OF THE CORE RESEARCH, OR THE CONDITION, OWNERSHIP, MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE OF THE CORE RESEARCH OR ANY INTELLECTUAL PROPERTY OR RESEARCH RESULTS, OR THAT USE OF INTELLECTUAL PROPERTY OR RESEARCH RESULTS WILL NOT INFRINGE ANY PATENT, COPYRIGHT, TRADEMARK OR OTHER INTELLECTUAL PROPERTY RIGHT OF A THIRD PARTY. EXCEPT AS SET FORTH IN SECTION 5.2, NO CORE INSTITUTION MEMBER SHALL BE LIABLE FOR ANY DIRECT, INDIRECT, CONSEQUENTIAL, PUNITIVE OR OTHER DAMAGES SUFFERED BY ANOTHER CORE INSTITUTION MEMBER RESULTING FROM THE CORE RESEARCH OR THE USE OF ANY INTELLECTUAL PROPERTY, ANY RESEARCH RESULTS OR ANY PRODUCTS RESULTING THEREFROM.

5.2 The Industry Member agrees to indemnify, defend, and hold harmless the Core Institution Members and their respective officers, directors, trustees, employees and agents ("Institution Indemnitees") against any and all claims, demands, actions, liability and expenses, related to or arising out of the Industry Member's breach of this Agreement; provided that the Industry Member's obligations pursuant to this Section 7.2 shall not apply to the extent such claims or suits result from the gross negligence or willful misconduct of any of Institution Indemnitees as determined by a court of law.

6. MISCELLANEOUS

6.1 All taxes and other contributions, fees, fiscal or para-fiscal contributions, imposts, duties, levies, fines, or charges, by whatever other name ("taxes") imposed by any government entity or a functional equivalent of a government entity and entailed by

laws, in connection or as a result of an Industry Member's payment of the Membership Fee, are the exclusive responsibility of the Industry Member and will be paid by the Industry Member.

6.2 No Center Member shall use the name, logo, seal, trademark, or service mark (including any adaptation of them) of any other Center Member, including any school, organization, employee, student or representative thereof, without the prior written consent of that Center Member. No Center Member except PENN shall use the name of the Center without the prior written consent of PENN.

6.3 For purposes of this Agreement and membership in the Center, the Center Members shall be independent contractors and none shall at any time be considered an agent or an employee of the other. No joint venture, partnership or like relationship is created between any of the Center Members by their membership in the Center or this Agreement.

6.4 The terms and provisions hereof shall inure to the benefit of, and be binding upon, the Center Members and their respective successors and permitted assigns. No Center Member may assign or transfer this Agreement or any of its rights or obligations created hereunder, by operation of law or otherwise, without the prior written consent of the other Parties. Any assignment not in accordance with this Section 6.3 shall be void.

6.5 A waiver by a Center Member of any of the terms and conditions of this Agreement in any instance shall not be deemed or construed to be a waiver of such term or condition for the future, or of any other term or condition hereof. All rights, remedies, undertakings, obligations and agreements contained in this Agreement shall be cumulative and none of them shall be in limitation of any other remedy, right, undertaking, obligation or agreement of a Center Member.

6.6 When possible, each provision of this Agreement will be interpreted in such manner as to be effective and valid under law, but if any provision of this Agreement is held to be prohibited by or invalid under law, such provision will be ineffective only to the extent of such prohibition or invalidity, without invalidating the remainder of this Agreement. The Center Members shall make a good faith effort to replace the invalid or unenforceable provision with a valid one which in its economic effect is most consistent with the invalid or unenforceable provision.

6.7 This Agreement constitutes the entire agreement between the Parties with respect to its subject matter, and supersedes all previous communications and agreements, whether oral or written, between the Parties with respect to the subject matter hereof. This Agreement may be waived, modified, or amended only by an instrument in writing and signed by duly authorized representatives of both Parties.

6.8 This Agreement may be executed in counterparts, each of which will be deemed an original, and all of which together will be deemed to be one and the same instrument. A portable document format (PDF) or electronic copy of this Agreement, including the signature pages, will be deemed an original.

IN WITNESS WHEREOF, the duly authorized representatives of the Parties hereby execute this Agreement as of the date first written above.

THE TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA

_____

By: _____

By: _____

Name: _____

Name: _____

Title:_____

Title: _____

ACKNOWLEDGED AS READ AND UNDERSTOOD BY CENTER DIRECTOR:

By: _____

Name: _____

Title:_____

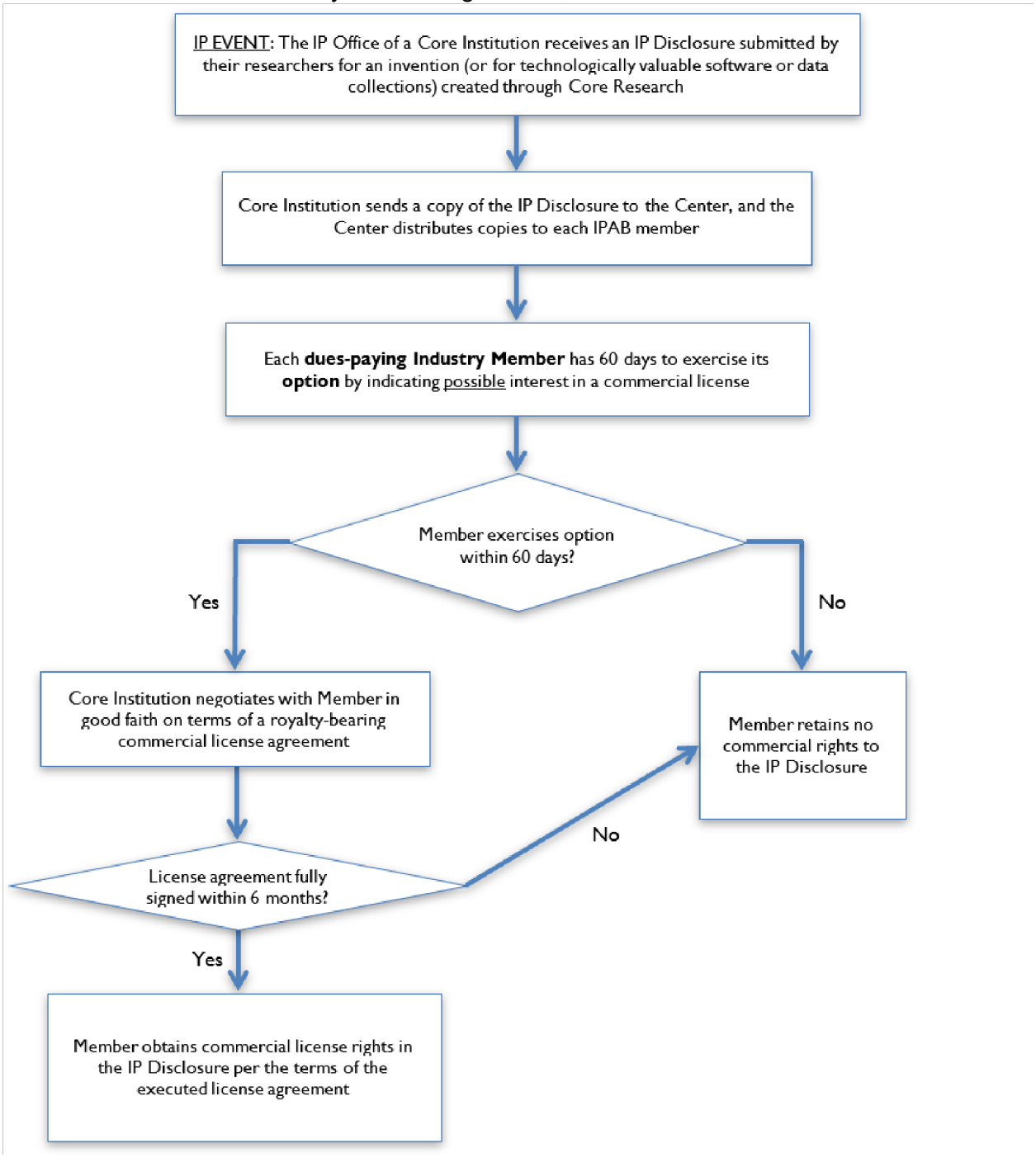
Ownership

- Ownership follows invention/authorship for new IP that is created through Core Research
- Ownership of IP that is not created through Core Research, such as background IP, is unaffected by participation in the Center

License Rights for IP that is Created through Core Research

- Internal Use License: Each Industry Member (excluding Non-Commercial Entities) is granted a non-exclusive, royalty-free, non-transferable license for non-commercial, internal research only
- Commercial License: Each Industry Member (excluding Non-Commercial Entities) is entitled to a non-transferable 60-day option to negotiate a royalty-bearing, non-exclusive license for commercial purposes o See flowchart on the following page for more details.
- US Government License: The US Government has certain rights set forth under the Bayh-Doyle Act and per NSF's implementing rules at 45 CFR §650.

Industry Member Agreement, Sections 3.4 – 3.5







EXEMPTION GRANTED

Ayesha Boyce
Division of Educational Leadership and Innovation - Tempe
-
Ayesha.Boyce@asu.edu

Dear Ayesha Boyce:

On 12/1/2022 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Evaluation of IoT4Ag
Investigator:	Ayesha Boyce
IRB ID:	STUDY00017082
Funding:	Name: National Science Foundation, Grant Office ID: FP00034804, Funding Source ID: 1941529
Grant Title:	FP00034804;
Grant ID:	FP00034804;
Documents Reviewed:	• Consent_Form_IoT4AgEvaluation_12_01_2022.pdf, Category: Consent Form; • Instruments_Surveys_IoT4AgEvaluation_11_28_2022.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • IRB Correspondance 12-01-2022, Category: Other; • IRB Social Behavioral - IoT4Ag - 12_01_2022.docx, Category: IRB Protocol; • Recruitment_Email_IoT4AgEvaluation_11_30_2022.pdf, Category: Recruitment Materials; • SOW, Category: Sponsor Attachment;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2)(ii) Tests, surveys, interviews, or observation (low risk) on 12/1/2022.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

Sincerely,

IRB Administrator

cc: Caitlin Albrechtsen Caitlin Albrechtsen
Mohammed Ibrahim

IPAB MEMBERSHIP CERTIFICATION

NSF Engineering Research Center
for the Internet of Things for Precision Agriculture (IoT4Ag)
Award EEC-1941529 (Penn ID 10074006)
Year 4 (9/1/2023-6/30/2024)

The signature below certifies that as of June 30, 2024, there are sixteen (16) Industrial/Practitioner Advisory Board (IPAB) members who both executed a membership agreement and paid a membership fee and/or provided an in-kind contribution since our last report.

Additional information related to the status of ERC Industry Member Agreements can be found in the Innovation Ecosystem section of the annual report.

Member Name	Membership Fee		In-Kind Contribution Value
	Received in Reporting Year (9/1/2023-6/30/2024)	Promised by End of Award Year (7/1/2024–08/31/24)	
AG SENSOR SOLUTIONS	$1,000		
AGRIBUGS, LLC			$2,500
AIGEN	$1,000		
BAYER CROPSCIENCE LP	$30,000		
DEERE AND CO.		$30,000	
FMC CORPORATION	$30,000		
HEADWALL PHOTONICS, INC.	$2,500		
PIONEER HI-BRED INTERNATIONAL	$30,000		
SUNSOUTH LLC	$2,500		
SYNGENTA GROUP	$30,000		
FARM-NG		$2,500	
MARVIL		$1,000	
NORDIC		$15,000	
SOILTECH WIRELESS			$2,000
FIXPOSITION AG			$5,000
TREFOS INC			$2,000
TOTAL	$127,000	$48,500	$11,500



Marissa McGeehan
Associate Director
Office of Research Services

8/13/2024
Date

Penn
University of Pennsylvania
Office of Research Services

Annual Cost-Share Certification

Project: NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)
NSF Award No.: 1941529 **Penn Proposal No.:** 10074006
Award Annual Period of Performance: 9/1/2020-8/31/2025
Reporting Period: 9/1/2023-6/30/2024

Institution	Committed		Amount of ERC Related Cost-Share	
	Full Period 9/1/2020-6/30/2024	Current Period 9/1/2023-6/30/2024	Full Period 9/1/2020-6/30/2024	Current Period 9/1/2023-6/30/2024
University of Pennsylvania	1,925,440	554,046	1,991,358	960,720
Purdue University*	770,468	178,052	729,219	138,470
University of California, Merced*	421,795	133,687	297,248	2,989
University of Florida*	826,228	204,937	345,230	64,956
TOTALS	3,943,931	1,070,722	3,363,055	1,167,135

*Reported through 5/31/2024

By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and objectives set forth in the terms and conditions of the Federal award. I am aware that any false, fictitious, or fraudulent information, or the omission of any material fact, may subject me to criminal, civil or administrative penalties for fraud, false statements, false claims or otherwise. (U.S. Code Title 18, Section 1001 and Title 31, Sections 3729-3730 and 3801-3812).

Marissa McGeehan
Associate Director

7/24/2024
Date

P221 Franklin Building 3451 Walnut Street Philadelphia, Pa 19104-6205
Tel 215.898.7293 Fax 215.898.9708 www.upenn.edu/researchservices/

University of Pennsylvania: Office of the Vice Provost for Research

University of Pennsylvania Policy on Conflicts of Interest related to Research (FCOI Policy)[1] Overview

Policy on Conflicts of Interest Related to Research

For several years, the University had two relevant policies pertaining to disclosure, assessment and management of *Investigators*' personal financial interests related to research. In 2011, federal regulation mandated significant changes to those policies. The University has recently developed a single uniform policy which not only reflects the new regulatory requirements, but also seeks to integrate and simplify certain aspects of the two previous policies. This unified policy – which supersedes the prior policies – defines the obligations of *Investigators* in Penn's research community and governs *Investigators*' financial interests / relationships related to their research, regardless of funding source. A summary of key policy provisions follows; however, *Investigators* engaged in research are responsible for reviewing the complete policy referenced above prior to participating in research at Penn.

Purpose. The purpose of this policy is to set forth the framework for identifying, evaluating, and managing financial conflicts of interest related to University research activities in order to minimize the risk of bias and to maintain integrity, credibility and respect for the work of Penn researchers.

Applicability. This policy is applicable to all research being conducted under the University's auspices, regardless of whether the research is externally or internally funded.

Disclosure Requirements[2] [3]

Each *Investigator* must disclose the following *Significant financial interests (SFIs)* (and those of his/her *Family members*) that reasonably appear to be related to the Investigator's *Institutional responsibilities:*

- For a public *Outside organization*: remuneration for the 12 months preceding the date of the disclosure plus the value of current equity that when aggregated exceed $5,000
- For a non-publicly traded *Outside organizat*ion: any equity (regardless of value) and remuneration for the 12 months preceding the date of the disclosure exceeding $5,000
- Income from intellectual property rights not assigned to Penn
- Any *Clinical trial intellectual property*, whether or not assigned to Penn
- Any *Fiduciary Role*

[1]The acronym FCOI (for Financial Conflict of Interest) reflects the policy's overall focus on the identification, evaluation and management of financial conflicts of interests.
[2]It is anticipated that the full implementation of the disclosure procedures in this policy will occur in stages, as necessary software and other resources are deployed to help support this process. Initial emphasis will be to first assure compliance with federal regulation and thereafter additional procedures will be phased in. The University will provide notice from time to time to its research community to advise of the specific means by which to submit disclosures.
[3]Defined terms are italicized with selected definitions provided at the end of the overview.

Investigators must disclose their *SFIs* at the time of proposal submission, annually, when added as an *Investigator* to an ongoing Public Health Service (PHS) project, and prior to participation in any PHS-funded research. *Investigators* are also required to timely update (within 30 days) their disclosures in the event of acquiring new *SFIs* or changes in their previously reported *SFIs*.

Investigators participating in research funded by the PHS must also disclose travel reimbursed or paid on the *Investigator's* behalf within the most recent 12 months, other than by an *Excluded Pay*er.

A *financial interest* is related to an *Investigator's Institutional responsibilities* if, for example, it arises from extramural activities that derive from the *Investigator*'s professional standing or are within that *Investigator*'s expertise in his or her professional field(s) of discipline, such as consulting, serving on a scientific advisory board, providing continuing professional education services, or serving as an expert witness for an *Outside organization* that, to the best of the *Investigator*'s knowledge, conducts or seeks to conduct business related to the *Investigator*'s field of discipline. In addition, equity in, or serving in a fiduciary role for, an *Outside organization* that, to the best of the *Investigator*'s knowledge, conducts or seeks to conduct business related to the *Investigator*'s field of discipline, is related to the *Investigator's Institutional responsibilities*.

Assessment of Disclosures. Each School will appoint an FCOI Office / Officer to review *SFI* disclosures and the *Investigator's* assessment of the relationship of the *SFIs* to the *Investigator's* research to determine which *SFI*s (if any) are related to the research. A determination of relatedness will be made based on the *Investigator's* assessment and/or on other facts deemed relevant by the School. If the School determines that one or more disclosed *SFI*s or travel relates to the research, the School shall direct the *Investigator* to submit information regarding those related *SFI*s to the University's Office of the Vice Provost for Research (OVPR) using such means of disclosure as prescribed by the OVPR (presently, the Financial Interest Disclosure Electronic System or FIDES).

For additional information, see *FCOI Disclosures in FIDES* and *Special Disclosure Process for PHS-funded Projects*

Determination of a Financial Conflict of Interest (FCOI). A *Financial Conflict of Interest* (*FCOI)* is an *SFI* that could directly and significantly affect the design, conduct, or reporting of the research. The University may utilize several forms of review to reasonably determine whether an *SFI* related to the research is an *FCOI,* including review by the Conflict of Interest Standing Committee (CISC), depending on the nature and value of the disclosed financial interests, as well as other factors.

Management of FCOIs, including FCOIs Involving Clinical Trials. An *SFI* found to constitute an *FCOI* may be subject to a management plan as a condition to the *Investigator's* participation in the research. The determination of whether an *FCOI* is manageable, including an *FCOI* involving a *Clinical Trial*, should take into account relevant factors, including but not limited to, the

uniqueness of the *Investigator*'s position with respect to the study, the nature and design of the research and the magnitude and nature of the *financial interest.* With respect to *Clinical Trials*, other relevant factors include the degree of risk to human subjects, the role of the *Investigator* in the study, the study's design, and the degree of the *Investigator's* influence upon the recruitment/ enrollment of subjects and/or the results of the study.

Training. *Investigators* must receive training from the University related to research-related *FCOI* prior to engaging in research at the University and at least every four years thereafter.

Requests from the Public Regarding FCOI Information. To the extent required by law (e.g., PHS regulations) or otherwise by the terms and conditions of a research award, in response to a written request for information related to *FCOIs* held by *senior/key personnel* of the particular research project specified in the request, the University will provide required information to the requestor.

Other Policy Provisions. In addition to the foregoing, the FCOI Policy includes other provisions as required by law, research sponsors and/or the University. These include FCOI disclosure and reporting requirements for sub-awards, the reporting of FCOIs to research sponsors (e.g., PHS agencies), as well as provisions to address noncompliance with the FCOI Policy.

Selected Definitions

Clinical trial shall have the same meaning as prescribed from time to time by the World Health Organization.

Clinical trial intellectual property means an *Investigator*'s interest in intellectual property that is the subject of a copyright, issued patent, or a patent application (regardless of whether the intellectual property has been patented, licensed, or assigned to the University) if such intellectual property is being tested, evaluated, or developed in, or if its commercial value could be affected by, the *Clinical trial* in which the *Investigator* is engaged or proposes to engage.

Excluded payer means a Federal, state, or local government agency, a United States institution of higher education, an academic teaching hospital, a medical center, or a research institute that is affiliated with an institution of higher education. By way of example, Children's Hospital of Philadelphia, the Philadelphia Veterans Affairs Medical Center, the Howard Hughes Medical Institute, and Wistar Institute are *Excluded payers*.

Family member means an *Investigator*'s spouse or dependent child. From to time, the *Institutional official* may amend the definition of *Family member* and notify the University research community prior to the effective date of such change.

Fiduciary role means membership on the governing board of an entity, including service on its board of directors, or having a position of authority or responsibility to act in the best interest of the entity, including being an officer, manager, partner, or limited liability company member with management responsibility.

Institutional official means the Vice Provost for Research or such other person as the Provost appoints from time as the individual within the University responsible to oversee the University's compliance with conflict of interest regulations and policies.

Institutional responsibilities means an *Investigator*'s professional or employment-related responsibilities on behalf of the University or any of its Schools, which may include research, research consultation, teaching, professional practice, institutional committee memberships, and service on panels such as Institutional Review Boards or Data and Safety Monitoring Boards.

Investigator means the project director or principal investigator and any other person, regardless of title or position, who is responsible for the design, conduct, or reporting of research, whether externally or internally funded, or proposed for such funding, which may include, for example, collaborators or consultants.

Outside organization means any organization other than the University or University of Pennsylvania Health System or its corporately-owned entities (*e.g.*, Clinical Care Associates and Clinical Practices of the University of Pennsylvania), and other than an *Excluded payer*.

Related Penn Policies

- Patent and Tangible Research Property Policies and Procedures of the University of Pennsylvania
- Consulting and Outside Activities Policies and Procedures of the University of Pennsylvania
- Policy Relating to Copyrights and Commitment of Effort for Faculty

For questions regarding FCOI, please contact Rich L. Shellenberger Jr., FCOI Program Coordinator, at (215) 898-3603 or by e-mail at coi@pobox.upenn.edu

RE: NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (EEC-1941529), Penn Reference No. 10074006, Cherie R Kagan, PI

To whom it may concern:

The University of Pennsylvania has a comprehensive written and enforced policy, the University of Pennsylvania Policy on Conflicts of Interest Related to Research (FCOI Policy) applicable to all research being conducted under the University's auspices. The purpose of this policy is to set forth the framework for identifying, evaluating, and managing Financial Conflicts of Interest related to University research activities to control their ability to create bias and to maintain integrity, credibility, and respect for the work of Penn researchers.

Under the FCOI Policy, Investigators (defined as is project director or principal investigator and any other person, regardless of title or position, who is responsible for the design, conduct, or reporting of Research, whether externally or internally funded, or proposed for such funding, which may include, for example, collaborators or consultants), must disclose any Significant Financial Interests as defined and as required under the FCOI Policy.

The University of Pennsylvania has determined that all Penn Investigators for the above award have submitted disclosures and that no Financial Conflicts of Interest have been identified.

Please let me know if you need further assistance.

Regards,

Joanne

Joanne Rosenthal
Associate Vice Provost for Research / Associate Counsel
Office of Research Compliance

Amy Camilleri, CRA
Senior Associate Director, Grants
Office of Research Services
08/03/2021

RESIDUAL BALANCE CERTIFICATION

NSF Engineering Research Center
for the Internet of Things for Precision Agriculture (IoT4Ag)
Award EEC-1941529 (Penn ID 10074006)
Reporting Period 9/1/2023-6/30/2024 (Year 4)

The signature below certifies that of the NSF award of $20,080,465 and Membership Fees of $437,950 collected thus far, we are projecting a total unexpended residual balance of $1,619,079 at the end of the budget period (8/31/2024). Of that balance, the full balance of $1,619,079 is committed, encumbered, or obligated towards the goals of the ERC.

Previous Award Year to Current Year Award			Current Award Year to Proposed Award Year		
Total Unexpended Residual Funds*		**$2,058,965**	**Total Projected Unexpended Residual Funds***		**$1,619,079**
NSF	$3,365,834		NSF	1,181,129	
Industry	$280,950		Industry	437,950	
Committed, Encumbered, Obligated Funds**		**$3,646,784**	**Committed, Encumbered, Obligated Funds****		**$1,619,079**
NSF	$3,365,834		NSF	1,181,129	
Industry	$280,950		Industry	437,950	
Residual Funds Without Specified Use		**$0**	**Residual Funds Without Specified Use**		**$0**
NSF	$0		NSF	$0	
Industry	$0		Industry	$0	

**Includes residual funds carried forward from previous year.*
***Includes full unexpended subcontract commitments*



Marissa McGeehan
Associate Director

8/27/2024

Date

APPENDIX III. PERSONNEL SUMMARY

The ERCWeb Personnel Summary Table 27 lists personnel at both the Center-wide summary level and the institutional level and begins on the next page.

Table: ERC Personnel																		
Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only								Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported						
Total All Institutions																		
Total [2]	202	126	69	7	4	0	15	75	30	4	1	6	61	6	19	10	0	7
Leadership/Administration																		
Directors	5	4	1	0	0	0	0	4	0	0	0	1	0	0	0	0	0	0
Research Thrust Leader	7	6	1	0	0	0	0	7	0	0	0	0	0	0	1	0	0	0
Engineering Workforce Development Program Leader	3	1	2	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0
Administrative Director	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Staff	2	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Student Leader	9	5	4	0	0	0	0	0	2	0	0	0	6	1	0	0	0	0
Diversity and Culture of Inclusion Program Leader	2	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1
Subtotal	**29**	**19**	**10**	**0**	**1**	**0**	**1**	**16**	**3**	**0**	**0**	**1**	**6**	**1**	**2**	**0**	**0**	**1**
Programmatic Personnel																		
Senior Faculty	27	20	7	0	1	0	1	23	1	0	0	1	0	0	4	0	0	1
Junior Faculty	7	4	3	0	0	0	0	3	1	0	0	0	2	1	0	0	0	2
Staff	11	7	4	0	0	0	1	4	2	0	0	0	4	0	0	0	0	0
Total Postdocs	11	7	3	1	1	0	0	0	2	0	0	0	7	1	1	1	0	0
Total Doctoral Students	65	38	25	2	0	0	4	17	6	1	0	1	34	2	3	6	0	1
Total Master's Students	15	12	2	1	1	0	0	3	1	0	0	1	9	0	1	1	0	0
Total Undergraduate Students	32	20	10	2	1	0	1	13	9	1	0	0	5	2	5	2	0	1
Other Visiting College Students	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only								Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported						
Subtotal	**169**	**109**	**54**	**6**	**4**	**0**	**8**	**63**	**22**	**2**	**0**	**3**	**61**	**6**	**14**	**10**	**0**	**5**
ERC REU Students																		
Center Funding Students	20	10	9	1	0	0	3	8	5	2	1	1	0	0	2	0	0	2
NSF REU Site Award Students	5	3	2	0	0	0	0	2	3	0	0	0	0	0	1	0	0	0
Other NSF Supplemental Funding Students	3	2	1	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0
Subtotal	**28**	**15**	**12**	**1**	**0**	**0**	**3**	**11**	**9**	**2**	**1**	**2**	**0**	**0**	**4**	**0**	**0**	**2**
Precollege (K-12)																		
Teachers (RET)	6	3	3	0	0	0	4	1	0	0	0	1	0	0	1	0	0	0
Subtotal	**6**	**3**	**3**	**0**	**0**	**0**	**4**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**
University of Pennsylvania - Lead Institution																		
Total [2]	62	41	19	2	2	0	5	15	15	0	0	1	23	1	2	1	0	0
Leadership/Administration																		
Directors	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Research Thrust Leader	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Engineering Workforce Development Program Leader	2	0	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Administrative Director	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Staff	2	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Student Leader	2	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Diversity and Culture of Inclusion Program Leader	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Subtotal	**12**	**7**	**5**	**0**	**1**	**0**	**1**	**7**	**2**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
Programmatic Personnel																		

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only								Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported						
Senior Faculty	8	6	2	0	1	0	0	6	1	0	0	0	0	0	1	0	0	0
Junior Faculty	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Staff	6	4	2	0	0	0	1	2	2	0	0	0	1	0	0	0	0	0
Total Postdocs	6	4	2	0	1	0	0	0	1	0	0	0	4	0	1	0	0	0
Total Doctoral Students	23	14	8	1	0	0	3	5	5	0	0	0	9	1	0	1	0	0
Total Master's Students	10	8	1	1	0	0	0	0	1	0	0	1	8	0	0	0	0	0
Total Undergraduate Students	7	3	4	0	0	0	1	1	5	0	0	0	0	0	0	0	0	0
Subtotal	**61**	**40**	**19**	**2**	**2**	**0**	**5**	**14**	**15**	**0**	**0**	**1**	**23**	**1**	**2**	**1**	**0**	**0**
ERC REU Students																		
Other NSF Supplemental Funding Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Purdue University - Core Partner																		
Total [2]	35	25	7	3	0	0	0	15	1	0	0	1	16	2	0	7	0	0
Leadership/Administration																		
Directors	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Research Thrust Leader	3	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Student Leader	3	2	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Subtotal	**7**	**5**	**2**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**1**	**3**	**0**	**0**	**0**	**0**	**0**
Programmatic Personnel																		
Senior Faculty	6	5	1	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Total Postdocs	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total Doctoral Students	16	10	5	1	0	0	0	3	0	0	0	0	13	0	0	5	0	0

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only								Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported						
Total Master's Students	3	3	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0	0
Total Undergraduate Students	8	5	1	2	0	0	0	4	1	0	0	0	1	2	0	1	0	0
Subtotal	**35**	**25**	**7**	**3**	**0**	**0**	**0**	**15**	**1**	**0**	**0**	**1**	**16**	**2**	**0**	**7**	**0**	**0**
ERC REU Students																		
NSF REU Site Award Students	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of California, Merced - Core Partner																		
Total [2]	24	15	9	0	1	0	1	9	5	1	0	1	6	0	6	0	0	3
Leadership/Administration																		
Directors	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Research Thrust Leader	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Student Leader	2	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Diversity and Culture of Inclusion Program Leader	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Subtotal	**5**	**3**	**2**	**0**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**
Programmatic Personnel																		
Senior Faculty	4	2	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	1
Junior Faculty	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Staff	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total Postdocs	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Doctoral Students	9	7	2	0	0	0	1	1	1	0	0	1	5	0	2	0	0	1
Total Undergraduate Students	8	5	3	0	1	0	0	3	3	1	0	0	0	0	4	0	0	0
Subtotal	**24**	**15**	**9**	**0**	**1**	**0**	**1**	**9**	**5**	**1**	**0**	**1**	**6**	**0**	**6**	**0**	**0**	**3**

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only								Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported						
University of Florida - Core Partner																		
Total [2]	42	27	14	1	1	0	0	23	1	0	0	0	14	3	5	2	0	2
Leadership/Administration																		
Directors	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Research Thrust Leader	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Engineering Workforce Development Program Leader	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Student Leader	2	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Subtotal	**5**	**4**	**1**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**0**
Programmatic Personnel																		
Senior Faculty	8	7	1	0	0	0	0	8	0	0	0	0	0	0	2	0	0	0
Junior Faculty	3	2	1	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1
Staff	4	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0
Total Postdocs	3	2	0	1	0	0	0	0	0	0	0	0	2	1	0	1	0	0
Total Doctoral Students	13	6	7	0	0	0	0	6	0	0	0	0	6	1	1	0	0	0
Total Master's Students	2	1	1	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0
Total Undergraduate Students	9	7	2	0	0	0	0	5	0	0	0	0	4	0	1	1	0	1
Subtotal	**42**	**27**	**14**	**1**	**1**	**0**	**0**	**23**	**1**	**0**	**0**	**0**	**14**	**3**	**5**	**2**	**0**	**2**
4-H Science and Adventure Camp - Collaborating Institution																		
AgrAbility - Collaborating Institution																		
Arizona State University - Collaborating Institution																		
Total [2]	5	1	4	0	0	0	1	2	0	1	0	0	1	0	1	0	0	0
Programmatic Personnel																		

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only													
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported	Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
Senior Faculty	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Total Doctoral Students	4	1	3	0	0	0	0	2	0	1	0	0	1	0	0	0	0	0
Subtotal	**5**	**1**	**4**	**0**	**0**	**0**	**1**	**2**	**0**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**
CalTeach - Collaborating Institution																		
Center for Information Technology Research in the Interest of Society (CITRIS) - Collaborating Institution																		
Community Alliance of Family Farmers - Collaborating Institution																		
Deaf Kids Code - Collaborating Institution																		
Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS) - Collaborating Institution																		
Pennsylvania Agriculture Cross-Sector Collaborative - Collaborating Institution																		
Tuskegee University - Collaborating Institution																		
University of Maryland Eastern Shore - Collaborating Institution																		
Total [2]	2	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
Programmatic Personnel																		
Junior Faculty	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Other Visiting College Students	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Walt Disney World - Collaborating Institution																		
California Polytechnic State University San Luis Obispo - Non-ERC Institution Providing REU Students																		
Total [2]	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
ERC REU Students																		

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only													
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported	Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
Center Funding Students	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Grinnell College - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
Illinois Institute of Technology - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Other NSF Supplemental Funding Students	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Merced College - Non-ERC Institution Providing REU Students																		
Total [2]	2	1	1	0	0	0	0	1	0	0	0	1	0	0	2	0	0	0
ERC REU Students																		
NSF REU Site Award Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Other NSF Supplemental Funding Students	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**2**	**0**	**0**	**0**
North Carolina State University at Raleigh - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
ERC REU Students																		
Center Funding Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only													
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported	Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
Northeastern University - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																		
NSF REU Site Award Students	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Northwestern University - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Pennsylvania State University-Main Campus - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Princeton University - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Santa Clara University - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Personnel Type	Total[1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only							Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported					
Santa Fe College - Non-ERC Institution Providing REU Students																	
Total [2]	2	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0
ERC REU Students																	
Center Funding Students	2	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Stevens Institute of Technology - Non-ERC Institution Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ERC REU Students																	
Center Funding Students	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Swarthmore College - Non-ERC Institution Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
ERC REU Students																	
Center Funding Students	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
Syracuse University - Non-ERC Institution Providing REU Students																	
Total [2]	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERC REU Students																	
Center Funding Students	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
The University of Texas at Dallas - Non-ERC Institution Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ERC REU Students																	
Center Funding Students	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only													
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported	Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
The University of Texas at El Paso - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**
University of Illinois at Urbana Champaign - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERC REU Students																		
NSF REU Site Award Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Maryland Baltimore County - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Pittsburgh - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Puerto Rico at Humacao - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
ERC REU Students																		
Center Funding Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only								Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported						
University of Tennessee Martin - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Texas at Austin - Non-ERC Institution Providing REU Students																		
Total [2]	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																		
NSF REU Site Award Students	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Villanova University - Non-ERC Institution Providing REU Students																		
Total [2]	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																		
Center Funding Students	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ivy Tech Community College of Indiana - Community College																		
BobCat Academy - Pre-college Partner																		
Cade Museum for Creativity and Invention - Pre-college Partner																		
Future Farmers of America - Pre-college Partner																		
Hamilton West High School - Pre-college Partner																		
Kensington High School - Pre-college Partner																		
Total [2]	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0

Personnel Type	Total[1]	Gender			Citizenship Status										Ethnicity: Hispanic			Disability
					Race-U.S. citizens and permanent residents only													
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	More than one race reported, non-minority	Race Not Reported	Citizenship Foreign/Temp Visa	Citizenship Not Reported	U.S. Citizen/Perm Resident	Citizenship Foreign/Temp Visa	Citizenship Not Reported	
Precollege (K-12)																		
Teachers (RET)	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**
Lankenau Environmental Science High School - Pre-college Partner																		
Total [2]	2	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Precollege (K-12)																		
Teachers (RET)	2	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**0**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Lower Merion High School - Pre-college Partner																		
Morris Arboretum - Pre-college Partner																		
National Agriculture in the Classroom - Pre-college Partner																		
Science Leadership Academy at Beeber - Pre-college Partner																		
Total [2]	2	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Precollege (K-12)																		
Teachers (RET)	2	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Student Science Training Program - Pre-college Partner																		
W.B. Saul High School of Agriculture - Pre-college Partner																		
Total [2]	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Precollege (K-12)																		
Teachers (RET)	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

[1] The Total column will not equal the sum of the values in each row. This is because an individual will be reported more than once across Gender, Citizenship Status, Ethnicity: Hispanic, and Disability.
[2] If ERC Personnel were entered at the individual level the Total row may not equal the sum of the line items. This is because an individual may be reported in more than one personnel category but is only counted once for the purposes of the Total.

Legend

AI/AN: American Indian or Alaska Native

NH/PI: Native Hawaiian or Other Pacific Islander

B/AA: Black/African American

W: White

A: Asian, e.g., Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian
More than one race reported, minority - Personnel reporting a) two or more race categories and

b) one or more of the reported categories includes American Indian or Alaska Native, Black or African American, or Native Hawaiian or Other Pacific Islander

More than one race reported, non-minority - Personnel reporting a) both White and Asian and
b) no other categories in addition to White and Asian

US/Perm: U.S. citizens and legal permanent residents

Non-US: Non-U.S. citizens/non-legal permanent residents

APPENDIX IV. BOARD, COUNCIL, COMMITTEE CHARTERS

Below are the Charters developed for IoT4Ag advisory boards and other key committees formed to provide feedback to the ERC.

Industrial Practitioner / Agricultural Systems Advisory Board (IPAB / ASAB)

BOARD COMPOSITION: The Industrial Practitioner and Agricultural Systems Advisory Boards (IPAB / ASAB) have been merged into one advisory board. This board is comprised of members representing industry, government and other innovation partners, and of members from commodity producer boards (row, vegetable, fruit and nut crops), crop consultant associations, farm cooperatives with precision Ag advisors, and Ag and horticulture extension agents.

CHARGE: The role of the combined advisory board is:

- *IPAB Members:* To advise the IoT4Ag Innovation Ecosystem Directors, the IoT4Ag Executive Committee, and the Research Systems Integration, Thrust, and Testbed Directors on IoT4Ag's product definition and deployment and on IoT4Ag's intellectual property and commercial and entrepreneurial activity.
- *ASAB Members:* To advise the IoT4Ag Innovation Directors, the IoT4Ag Executive Committee, and the Research Systems Integration, Thrust, and Testbed Directors on IoT4Ag's product definition, deployment, and adoption.
- *IPAB Members:* To collaborate in creating and maintain a Technology Outlook and Roadmap for Precision Agriculture.
- *ASAB Members:* To participate in IoT4Ag technology demonstrations.
- *IPAB and ASAB Members:* To provide mentorship of IoT4Ag students.
- *IPAB and ASAB Members:* To perform yearly SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the IoT4Ag value proposition.

RESPONSIBILITY OF IPAB / ASAB: The IPAB / ASAB will meet with the IoT4Ag leadership biannually to guide the research, workforce, diversity/inclusion, and innovation activities of the Center. Meetings may be in-person or virtual.

The IPAB / ASAB will develop an annual SWOT analysis and will present the analysis to the National Science Foundation (NSF) site visit team. The IPAB will participate in the annual meeting, expected to be held in the fall.

The IPAB / ASAB will review the progress on the Center's projects and will provide input on the Center's strategic plans.

IoT4Ag OBLIGATIONS: The IoT4Ag Center will provide as much advance notice as possible of meetings and video conferences.

IoT4Ag will provide to the board members, in a timely fashion:

- Relevant sections of the NSF Annual Report in advance of the annual site visit.
- Both the slides to be presented during the NSF Site Team Visit in advance of the visit and slides that are presented in response to the NSF Site Team questions that arise at the annual meeting.
- Online access to research project briefs and research results to help keep the board members informed and facilitate comments as appropriate.
- Periodic updates listing new publications and presentations emanating from the different research projects.

Council of Dean's

COUNCIL COMPOSITION: The Council of Deans will comprise four (4) members and will be the Dean from each partner institution, except if the Dean is a member of the Center, then the Vice Provost of Research will replace that Dean.

CHARGE: The purpose of the Council of Deans is as follows:

- To advise the Center's leadership team on its efforts, including research, education, diversity and inclusion, and innovation ecosystem.
- To ensure compliance with university, school, and departmental policies.
- To support the Center in its efforts as noted above.
- To promote the Center's activities.

RESPONSIBILITY OF DEAN'S COUNCIL: The Council of Deans will meet once a year at the NSF site visit typically held in the Fall in Philadelphia, PA (or virtually) and through quarterly virtual meetings. The Council's members may be asked to meet in addition to video conference calls to provide specific guidance and advice.

The Council will advise the Center's leadership team on research, education, diversity and inclusion, and innovation activities. The Council will ensure that the Center's activities follow each partner institution's university, school, and departmental policies. The Council will support the Center's efforts in each of the four pillars noted above and will promote the Center's activities within each institution.

IoT4Ag OBLIGATIONS: The Center for the Internet of Things for Precision Agriculture (IoT4Ag) will provide as much advance notice as possible about meetings and video conferences.

IoT4Ag will provide to the Council members, in a timely fashion:

- Relevant sections of the NSF Annual Report in advance of the annual site visit.
- Both the slides to be presented during the NSF Site Team Visit in advance of the visit and slides that are presented in response to the NSF Site Team questions that arise at the annual meeting.
- Online access to research project briefs and research results, workforce development and diversity and culture of inclusion activities, and intellectual property and industry and entrepreneurial engagement to help keep the Council informed and facilitate comments as appropriate.

Engineering Workforce Development (EWD) / Diversity & Culture of Inclusion (DCI) Advisory Board

BOARD COMPOSITION: The Engineering Workforce Development (EWD) and Diversity & Culture of Inclusion (DCI) Advisory Board have been merged into one advisory board. The DCI members will be comprised of one (1) representative from each partner institution, two (2) external academic members, and one (1) graduate student from the Center membership for a total of seven (7) members. The EWD members will be comprised of seven (7) members, including four (4) non-IoT4Ag experts in education, extension, and outreach from each partner institution, one (1) K-12 representative, one (1) community college representative, and one (1) graduate student from the Center membership.

CHARGE: The role of the DCI / EWD Advisory Board is:

- *DCI Members:* To advise the Diversity and Culture of Inclusion (DCI) Directors and the IoT4Ag Executive Committee on DCI's recruitment, education, and retention of students, faculty, and Advisory Board members, and realize a sustained positive impact on science and engineering.
- *EWD Members:* To advise the Workforce Development Directors and IoT4Ag Executive Committee on IoT4Ag's technical and professional educational programming.
- *EWD / DCI Members:* To provide feedback and contribute to Center assessment, specifically as it relates to the DCI and EWD pillar.
- *EWD / DCI Members:* To contribute to Center and NSF DCI presentations, as time permits.
- *EWD / DCI Members*: To perform yearly SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of the IoT4Ag DCI program.

RESPONSIBILITYOF EWD / DCI ADVISORY BOARD: The advisory board will meet a minimum of two times a year, either virtually or in person. Attendance is expected at the annual NSF site visit in Philadelphia, PA each Fall. The members, or a subset, may be asked to meet through video conference calls one to two times per year to provide specific guidance and advice. Examples might include, but are not limited to the EWD / DCI co-Directors, Leadership Team, Assessment, and Student Leadership Council.

The DCI members will provide guidance and advice to the DCI ERC Co-Directors on IoT4Ag DCI activities to facilitate a culture of inclusion and transformative impacts on engineering and science. The DCI members will also review the evaluation and assessment tools and metrics to ensure that the Center captures relevant data and, thus, improve its efforts to attain diversity goals and to facilitate a culture of inclusion.

The EWD members will provide guidance and advice to the EWD Directors on the IoT4Ag Center activities as it relates to the workforce development activities in its efforts to reach its goals.

All members will provide, at minimum, a SWOT analysis (Strengths, Weaknesses, Opportunities, and Weaknesses) of these efforts at the NSF site visit.

IoT4Ag OBLIGATIONS: The Center for the Internet of Things for Precision Agriculture (IoT4Ag) will provide as much advance notice as possible of meetings and video conferences. IoT4Ag will pay all travel expenses and provide board members with an honorarium of $500 for attendance and participation in the annual NSF Site Visit in the fall.

IoT4Ag will provide to DCIAB members, in a timely fashion:

- Relevant sections of the NSF Annual Report in advance of the annual site visit.
- Slide decks and written materials in advance of, and in response to, the annual NSF Site Team Visit.
- Online access to research project briefs, research results, demographic statistics, and other relevant information to keep the EWD / DCI advisory board members informed and to facilitate input.
- Materials as requested by EWD / DCI advisory board members.

Science Advisory Board (SAB)

BOARD COMPOSITION: The Scientific Advisory Board (SAB) will be comprised of six (6) members including experts in IoT4Ag-relevant fields such as industry, government, and academic members that represent the science, engineering and socioeconomics needed for a

convergent understanding of the impacts and opportunities of physical and cyber-physical system-enabled precision agriculture. All members will be external to the IoT4Ag center.

CHARGE: The role of the Scientific Advisory Board (SAB) is:

- To perform yearly SWOT analysis of the IoT4Ag value proposition.
- To provide the IoT4Ag Executive Committee input on the science and technology aspects of the strategic direction of the IoT4Ag.
- To advise the Leadership team on technical barriers to advancement of IoT4Ag projects.
- To provide Senior Investigators input on the science and technology aspects of their IoT4Ag projects.

RESPONSIBILITY OF SCIENTIFIC ADVISORY BOARD: The SAB will meet two times a year, including the NSF site visit typically held in the Fall in Philadelphia, PA (or virtually). The SAB members, or a subset, may be asked to meet additionally in video conference calls one to two times to provide specific guidance and advice.

In addition to the general meetings described above, each SAB member will serve as liaison to core research projects, i.e., projects supported with NSF funding. Project assignment will be subject to mutual agreement of the senior investigator, the SAB member and the IoT4Ag team. Each will also have at least one Industry Advisory Board (IAB) liaison. The senior investigators on a project will be responsible for contacting and briefing their SAB liaisons on a quarterly basis on their research progress. The form of the briefing (e.g., telephone call, PowerPoint presentation, technical memorandum, face to face at CBBG meetings) will be determined by mutual agreement of the SAB member and Senior Investigator. SAB briefings may also include the IAB liaison if mutually agreed upon by all involved parties.

The SAB will provide a SWOT analysis (Strengths, Weaknesses, Opportunities, and Weaknesses) of these efforts described above at the NSF site visit.

IoT4Ag OBLIGATIONS: The Center of the Internet of Things for Precision Agriculture (IoT4Ag) will provide as much advance notice as possible of meetings and video conferences. IoT4Ag will pay all travel expenses and provide board members with an honorarium of $500 for attendance and participation in the annual NSF Site Visit in the fall.

IoT4Ag will provide to the board members, in a timely fashion:

- Relevant sections of the NSF Annual Report in advance of the annual site visit.
- Both the slides to be presented during the NSF Site Team Visit in advance of the visit and slides that are presented in response to the NSF Site Team questions that arise at the annual meeting.
- Online access to research project briefs and research results to help keep the board members informed and facilitate comments as appropriate.

- Periodic updates listing new publications and presentations emanating from the different research projects.

Student and Postdoc Leadership Council (SLC)

COUNCIL COMPOSITION: The Student and Postdoc Leadership Council (SPLC) for the Center of the Internet of Things for Precision Agriculture (IoT4Ag) is comprised of nine (9) members from the four partner institutions.

CHARGE: The purpose of the Student and Postdoc Leadership Council (SPLC) is as follows:

- To serve as a liaison between the student community and the Center's leadership team.
- To encourage students to network, collaborate, and build friendships.
- To educate and mentor students.
- To promote connections and opportunities between students and industry.
- To conduct an annual SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of research, education, diversity and culture of inclusion, and industry and entrepreneurial activities.

RESPONSIBILITY OF STUDENT AND POSTDOC LEADERSHIP COUNCIL (SPLC): The SPLC will meet six times a year, including at the annual NSF site visit typically held in the Fall in Philadelphia, PA (or virtually) and at the IoT4Ag Center meeting, to be held annually and to rotate amongst partner sites. The SPLC members, or a subset, may be asked to meet additionally in video conference calls to provide specific guidance and advice.

The SPLC will serve as a liaison between the student community and the Center's leadership team to provide guidance and advice to enhance the student's experiences in the following areas: research, education, diversity and inclusion, and industry and entrepreneurial activities. In that regard, the SLC will conduct a SWOT analysis and submit a report to the Center, as part of the feedback cycle of program evaluation and improvement, and for the annual NSF site visit, to document the Center's efforts in the listed areas as noted above.

The SPLC will encourage and facilitate a student network to collaborate and build friendships across the Center, and will promote hierarchical, peer-to-peer student mentorship and faculty-student mentorship. The SLC will work with the Innovation Ecosystem to promote connections and opportunities between students and industry, government, and innovation partners.

The SPLC may also reach out to SPLC's at other Engineering Research Centers (ERC's) to share charges, activities, and experiences to enhance or improve the IoT4Ag ERC and to create connections and student relationships across the ERC network.

ROLES:

- President
- Vice President
- EWD Liaison Officer
- DCI Liaison Officer
- Innovation Ecosystem Liaison Officer
- Postdoctoral Fellow Representative
- Campus Liaisons

The SPLC may determine if other roles are needed. The Administrative Director will assist the SPLC to collect information from the other ERC SPLC's to review their structures and roles as needed.

ELECTIONS: The Site Directors from each partner institution will put forth the names of students from their institutions to join the SPLC each year. The presidential line will rotate yearly amongst partner institutions, and the Vice President will be from a different institution from and succeed the President in the following year. The SPLC will hold internal elections to name the other officers noted above. The term for each office starts after the NSF annual site visit. Offices will be identified/elected annually by September 1 to allow the officers to work with the incumbents through the annual review process.

IoT4Ag OBLIGATIONS: The Center for the Internet of Things for Precision Agriculture (IoT4Ag) will provide as much advance notice as possible of meetings and video conferences if requested by the leadership team.

IoT4Ag will pay all travel expenses as it relates to the NSF annual site visit and to IoT4Ag Center meetings. All other meetings will be virtual. The Administrative Director may assist with scheduling zoom calls as needed and/or set up a Slack channel for file sharing, communications, and virtual meetings.

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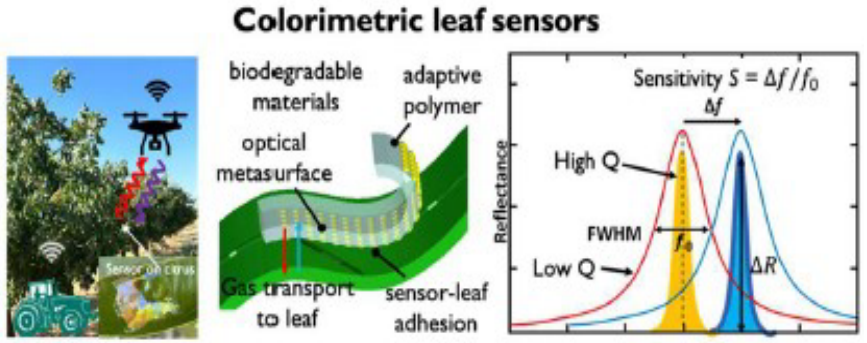
Project Title: 1_LEAFSENSE: Leaf Moisture and Temperature Sensors
Thrust(s): Thrust 1

Faculty Investigators: Cherie Kagan, Kevin Turner, Paulo Arratia (Penn), Reza Ehsani (Merced), Ian Small (UF)



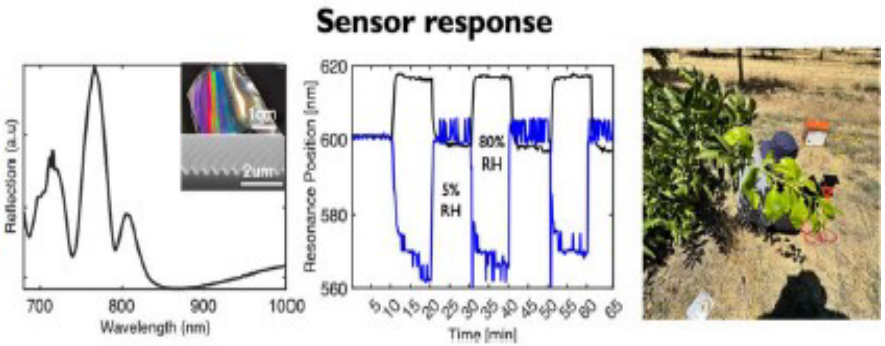
Outcome / Accomplishments (last three years):

- YR1-2: Developed scalable, low-cost nanocrystal (NC)-based imprinting for single-step fabrication of colorimetric sensors. Designed and fabricated nanostructures to resonate in visible and NIR.
- YR3: Fabricated leaf sensors using water-based TiO2 NC inks on moisture sensitive Chitosan substrates. Conducted field tests in Merced to characterize leaf adhesion.
- YR4: Performed leaf level tests in lab, greenhouse, and orchard in collaboration with 2_Optical Zoom with flexible, adhesive moisture-responsive colorimetric sensors to determine minimum sensor FOM and resonant spectra requirements for outdoor detection of leaf wetness. Co-optimized TiO_2 NC metasurface design and imprinting on custom leaf-compatible substrates and incorporated adaptive polymers in the metasurface for increasing sensitivity towards maximizing sensor FOM.
- Published a paper (DOI: 10.1021/acsanm.3c03507) in YR4; filed IP (US Provisional Application #63/378,980 in YR3 and #63/535,810 in YR4).



Impact & Benefits:

- Sensors can be deployed to spatially and temporally map local humidity levels at low-cost and without a power source.
- Sensor platform can be readily extended to measure multiple desired environmental parameters, to create "optical noses" for leaf health sensing.
- Sensor fabrication can be readily extended to other materials and designs to optimize for high FOM while ensuring sustainable and low-cost manufacturing.



Project Title: 2_OPTICAL ZOOM: Sensor and Detector

Thrust(s): Thrust 1 / Thrust 3

Faculty Investigators: Sanjeev Koppal (Florida), Vijay Kumar, Cherie Kagan (Penn)



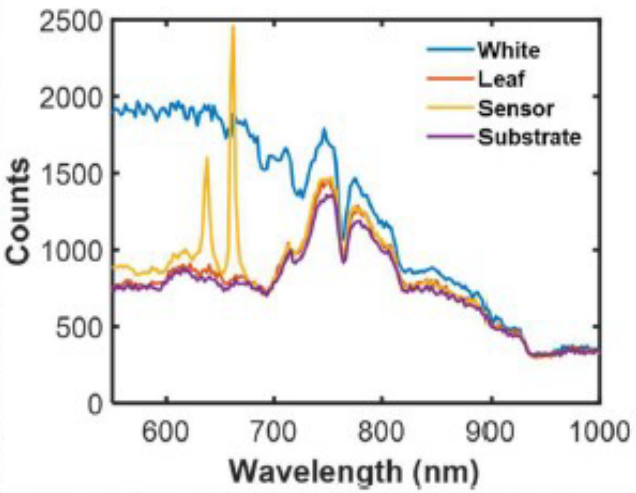
Outcome / Accomplishments (last three years):

- Y1: Integration of robot platform with SpectralZoom camera (previous Project 30) Y2: integration of on-board GPS unit and tracking camera to enable high-accuracy, GPS-IMU or VIO based localization and navigation.
- Y3: Indoor demonstration of complete imaging pipeline.
- Y3: Outdoor measurement of sensor's resonance with SpectralZoom camera.

Impact & Benefits:

- Low-cost colorimetric sensors developed by Project 1–LeafSense that will be deployed in the field to directly measure environmental conditions that affect crop resiliency should be more informative than traditional remote sensing methods.
- Our end-to-end robotic imaging pipeline is crucial to collecting spectral/plant health information from the novel colorimetric sensors deployed in the field.











Project Title: 3_SUBSURFACE SENSE: Passive, Sub-Surface Biodegradable Sensors and Components

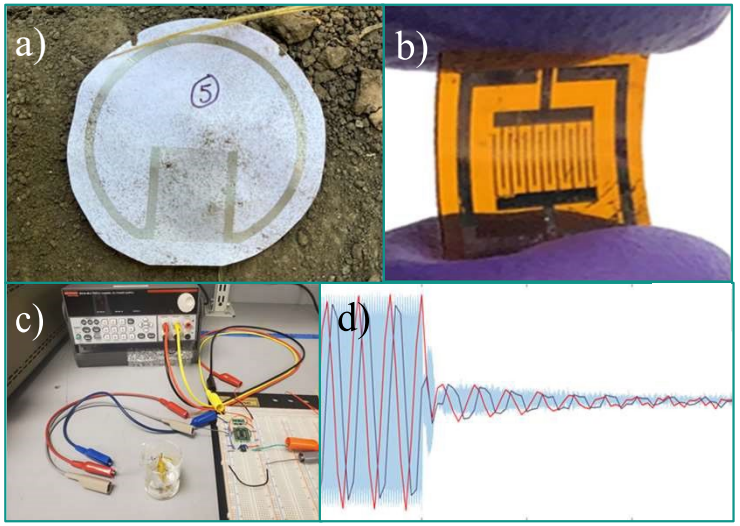
Thrust(s): Thrust 1 / Thrust 2

Faculty Investigators: Troy Olsson, Mark Allen, Cherie Kagan, Kevin Turner (Penn)



Outcome / Accomplishments (last three years):

- Y2: Developed a fully biodegradable nanocellulose coated paper substrate that enables screen printed electronics with comparable performance to polymer substrates
- Y4: Demonstrated passive wireless sensing scheme at distances up to 5 feet using a tiny acoustic wave resonator
- Y4: Fabricated air-stable RF sensors operating in the 902928 MHz range using room temperature treated Cu NC inks
- Y4: Deployed fully biodegradable wireless soil moisture sensors in an agricultural field for a one-week period
- Y4: Tested phosphate sensor in water samples sourced from agricultural areas, such as irrigation canals and tile drains
- Y4: Tested nitrate sensor in aqueous solution over concentrations typically found in soils Impact & Benefits:
- High spatial resolution monitoring of soil moisture, nutrient levels, and other parameters
- Enable farmers to input fewer resources, saving money and reducing environmental impact

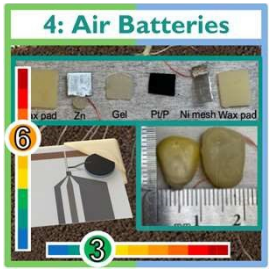


a) wireless soil moisture sensor after a 72h field test, b) Cu ink moisture sensor
c) phosphate sensor and potentiostat circuit
d) wireless interrogation of passive wireless scheme using acoustic resonator range extender

Project Title: 4_AIR-BATTERIES: Biodegradable Air Batteries for Distributed Sensing

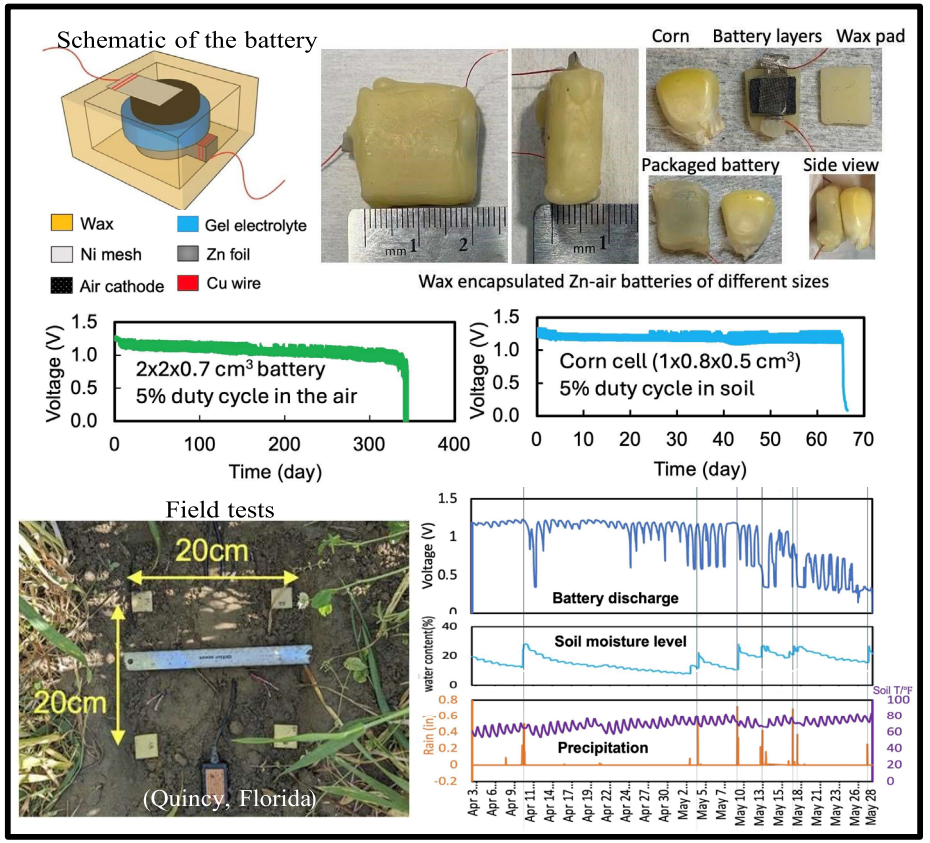
Thrust(s): Thrust 2 / Thrust 1

Faculty Investigators: Mark Allen, Troy Olsson (Penn), Tony Vyn (Purdue)



Outcome / Accomplishments (last three years):

- YR1-2: Designed and fabricated primary Zn-air batteries from biodegradable materials (Zn, gel electrolyte, carbon-based cathode, and biowaxes). Developed the testing protocols.
- YR3: Engineer the battery (2x2x0.7 cm ^{3}) gel electrolyte and cathode to extend its lifetime to 50 days in soil and 70 days in the air. Miniaturized cell to corn size (1x0.8x0.5 cm ^{3}).
- YR4: Corn cell's lifetime extended to 65 days in soil and 82 days in the air using corrosion inhibitor Maltodextrin under 5% duty cycle. 2x2x0.7 cm ^{3} battery's lifetime extended to 235 days in soil and 340 days in the air using neutral gel under 5% duty cycle. Batteries integrated with LoRaWAN and discharged for up to 50 days in Quincy, Florida testbed.



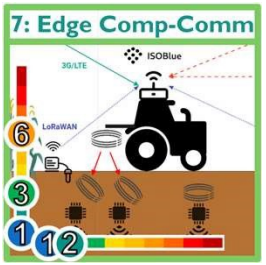
Impact & Benefits:

- Provide power to seasons-long operational field-deployed active sensors for high-resolution environmental data collection.
- Battery's biodegradable nature allows eco-friendly disposal, reducing recollection efforts and costs.
- An enabling tech for sensor and communication/Thrust 1 projects (Subsurface Sense)

Project Title: 7_EDGE COMP-COMM: Computing and Communication for Agricultural Sensors

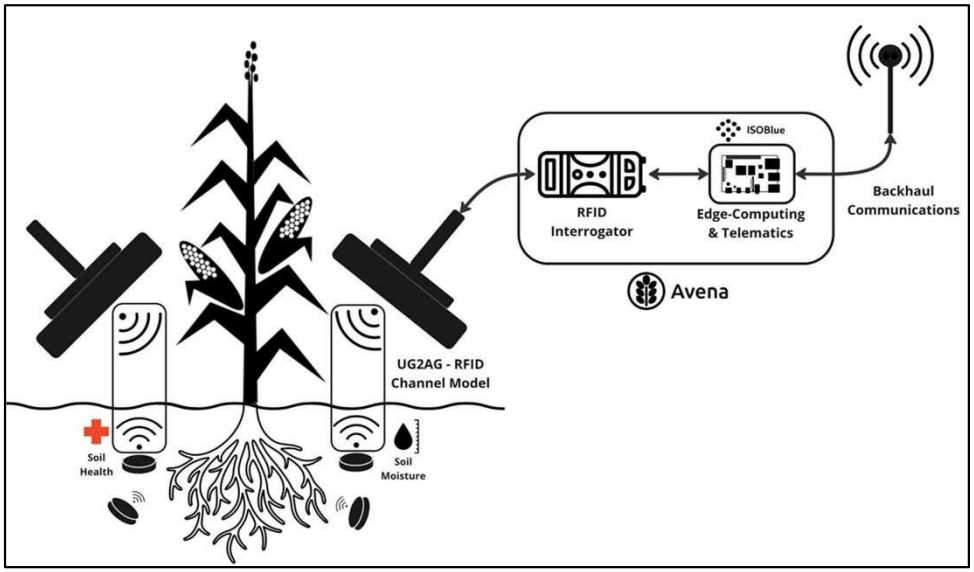
Thrust(s): Thrust 2

Faculty Investigators: Jim Krogmeier, David Love, Dennis Buckmaster (Purdue)



Outcome / Accomplishments (last three years):

- YR1: Designed, simulated, and characterized performance for inductive wireless powered communications for agricultural sensor devices based on load design and waveform optimization.
- YR2: Developed theoretical notions and coding schemes of capacity subject to an adversary's capabilities, in which adversaries attempt to corrupt sensor signals.
- YR3: Designed and developed a platform for underground communications with agricultural machinery based on the ISOBlue edge-computer and the Avena software stack, using RFID as the technology for sensor to machine communications with off-the-shelf equipment.



Impact & Benefits:

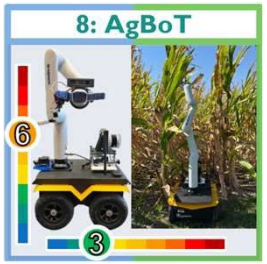
- A framework for WPCNs that captures network properties with a small number of measurable parameters
  - Secure communications approaches without sophisticated high-layer encryption
  - Sensor deployments with minimal environmental disruption and reduced exposure to above-ground hazards, large potential coverage due to highly scalable sensor deployments, and passive-powered sensors enable battery-less operation

Radio Frequency Identification (RFID) backscatter communications can be used to estimate signals such as soil moisture and soil health from parameters that affect the underground to aboveground communications channel. Experimental trials are used to build a communications channel model considering practical deployment implications, such as transponder depth, orientation, and footprint.

Project Title: 8_AGBOT: Crop Sampling Unmanned Ground Vehicle (UGV)

Thrust(s): Thrust 1 / Thrust 2

Faculty Investigators: David Cappelleri, Melba Crawford, Dan Quinn, Jim Krogmeier, Tony Vyn (Purdue); Vijay Kumar (Penn)



Outcome / Accomplishments (last three years):

- YR2: Corn stalk height and radius estimation algorithms
- YR2 – YR3: Designed and prototyped and UGV platform capable of in-row and under-canopy navigation and physical sampling in corn fields; updated sensor suite.
- YR3- YR4: Developed P-AgSLAM: a LiDAR-based algorithm for simultaneous localization and mapping in corn fields; Validated in simulation and in testbed
- YR3 - YR4: Deep Learning-based Leaf Detection for Robotic Physical Sampling: Mask R-CNN and YOLOv5 approach. Transformer-based approach
- YR4: Corn stalk ear height estimation algorithm
- YR4:L P-AgNAV: a LiDAR-based navigation algorithm utilizing range-view images and model predictive control; validated in simulation

Impact & Benefits:

- Timely and dense crop scouting is essential for targeted in-field interventions. Today this task is very labor intensive, less likely to adequately characterize actual field variability and overlaps with other farm operations.
- Existing robotic platforms are not capable to fit inside crop rows or under the canopy; others that drive above crops are too heavy to be deployed at regular intervals due to possibility for soil compaction.



Project Title: 9_SEMANTIC MAPPING: Semantic Mapping of Orchards for Yield Estimation

Thrust(s): Thrust 1 / Thrust 3

Faculty Investigators: Vijay Kumar, Pratik Chaudhari (Penn), Reza Ehsani (Merced), Dave Cappelleri (Purdue)

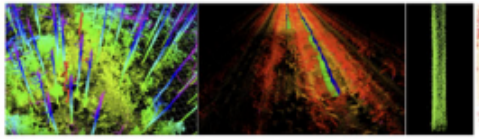


Outcome / Accomplishments (last three years)

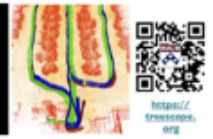
- YR2 – YR4: Created and open-source an **autonomous UAV software-hardware system** for long-range navigation in under-canopy environments.
- YR3: Created **TreeScope**, a robotics dataset for agricultural environments.
- YR4: Developed **SlideSLAM** for real-time decentralized metric-semantic mapping by heterogeneous robot teams.
- YR4: Built a system for fine-grained metric-semantic mapping and **diameter profile estimation** in under-canopy environments.
- YR4: Created a system for **constructing 4D metric semantic maps** of orchards for reliable yield estimation and change monitoring.
- YR4: **Monocular, event-based visual-inertial odometry**: A first-principles approach to building features of event stream, and a VIO pipeline. Unsupervised RGB VIO without ground-truth pose supervision.
- YR4: **Photorealistic maps of trees and foliage using neural radiance fields** with 360-degree cameras. Fine-tuned the approach for foliage and sparse views.
- YR4: **Active Perception for autonomous exploration** of an unknown environment. Demonstrated in simulated environments and real experiments on multiple robots.



Autonomous UAV System



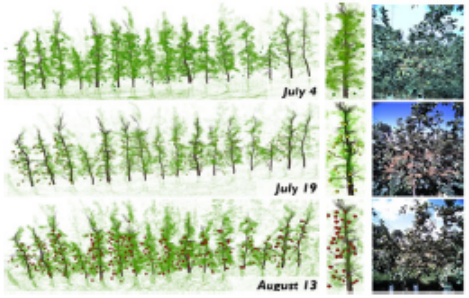
Variety of pine & oak in various forests / orchards
1,800 ground-truth field measurements of tree diameters



2.2 TB of data collected by UAVs and ground platforms across 10 hours and 50 hectares



Collaborative Metric-Semantic Mapping of Forests (3 robots, 860 trees, ~160,000 sq. m.)

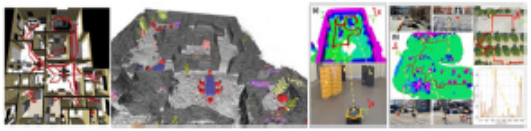


4D Metric-Semantic Map of an Apple Orchard. Each row corresponds to a different time session. Each sphere indicates a fruit's position and size. Brown meshes indicate tree trunk and branches.

Digital Twins



Active Perception: Autonomous Exploration for Data Collection.



Predictive information maximization as a guiding principle for active perception

$\hat{u}_{future} \in \underset{u_{future}}{\operatorname{argmax}}\, I(y_{future}; y_{past})$.

Robust exploration through online learning. Indoor and outdoor experiments on an unmanned ground vehicle.

Impact & Benefits

- The release of TreeScope provides valuable data for advancing agricultural robotics research.
- Fine-grained modeling of plants and trees for yield estimation and health monitoring.
- Robust autonomous mapping by a team of multiple robots, with flying and ground vehicles.
- By open-sourcing our autonomous UAV navigation and mapping code, we have significantly lowered the barrier of entry for researchers to deploy autonomous robots in agricultural fields.
- Our robust 4D metric-semantic metric-semantic mapping enables reliable, long-term monitoring of environmental changes in orchards.

Project Title: 10_PATH PLANNING: Informed Path Planning for Data Collection in Orchards

Thrust(s): Thrust 1 / Thrust 3

Faculty Investigators: Stefano Carpin, Reza Ehsani (UC Merced); Vijay Kumar (Penn)



Outcome / Accomplishments (last four years):

- YR1 – YR4: Developed planning algorithms for single and multiple robots to robustly collect data at scale in orchards. Different planning modalities have been explored with fundamental contributions to resource constrained planning .
- YR3 – YR4: Implemented and tested algorithms on robotic platforms operating in orchards and integrated with a self developed autonomous navigation stack tailored for agricultural environments .



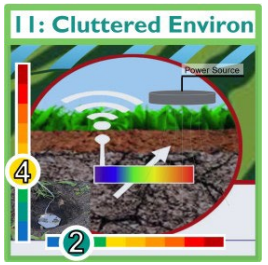
Impact & Benefits:

- YR4: Data collection at scale, enabled by the algorithms and systems developed as part of this project, is being used to assess water stress at a scale and granularity previously unattainable .
- Long term benefits include water use reduction for a more sustainable farming.

Project Title: 11_CLUTTERED ENVIRONMENTS: Wireless Charging of Electronics in Cluttered Environments

Thrust(s): Thrust 2

Faculty Investigators: David Arnold, Bill Eisenstadt (Florida)

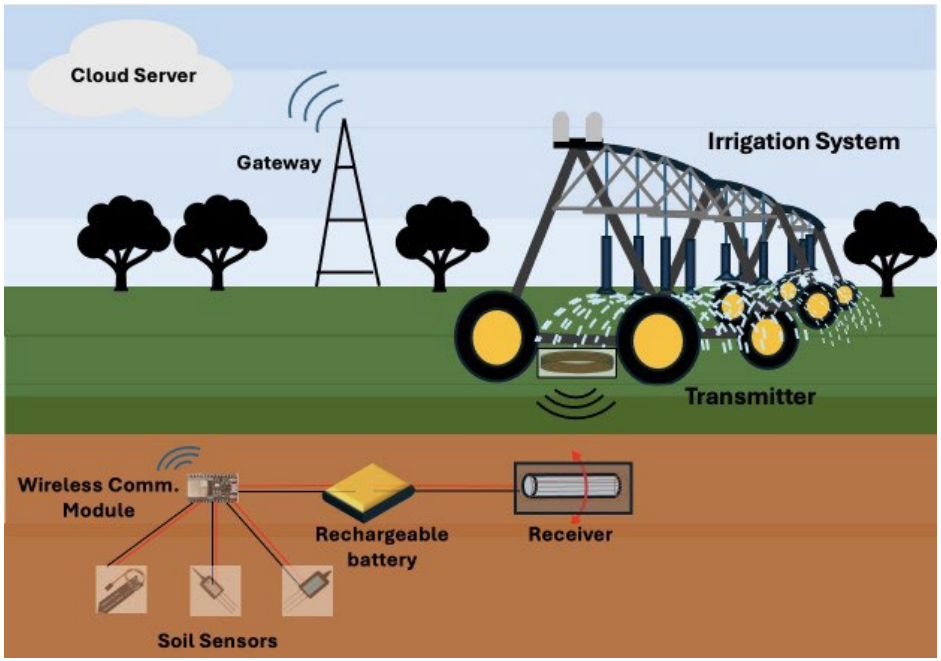


Outcome / Accomplishments (last three years):

- YR2 – YR3: Variety of wireless power transfer (WPT) receivers have been developed:
  - YR2: Miniature chip sized resonating magnet receivers.
  - YR3: Larger powerful rotating magnet receivers.
- YR4: Wireless Power Transfer has been achieved across a distance of 30 cm/~1 foot.
- YR4: Using rotating magnet receiver to power a buried soil moisture sensor system.

Impact & Benefits:

- Wireless power transfer to buried electronics can eliminate the need for power cords that clutter the soil.
- Autonomous recharging of batteries at periodic intervals to power buried sensor systems can minimize human intervention in replacing batteries.
- Achieving power transfer at extended distances enables us to power sensors that are buried deep in the soil.



Project Title: 12_ROBOT POWER: Autonomous Wireless Charging of Drones

Thrust(s): Thrust 2 / Thrust 1

Faculty Investigators: Sue Ann Bidstrup -Allen, Mark Allen (Penn), David Arnold (Florida)

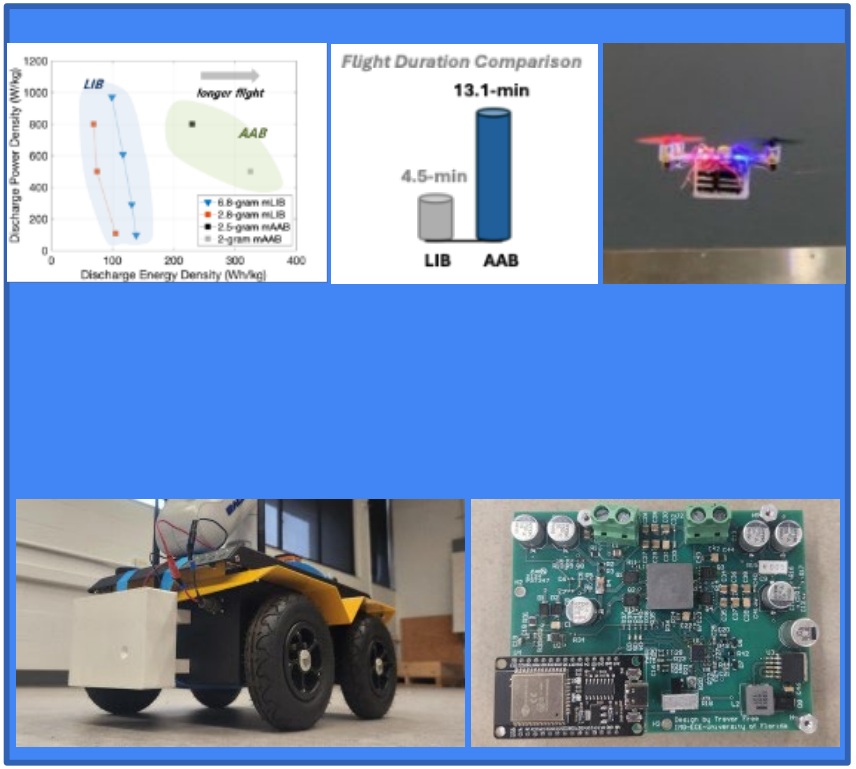


Outcome / Accomplishments (last three years):

- YR4: Developed Al-air batteries (AABs) with energy density of 320 Wh/kg, significantly surpassing the performance of equivalent commercial Li-ion batteries (LIBs).
- YR4: Demonstrated the untethered flight of AAB-powered centimeter-scale quadrotors, achieving a flight duration of 13.1 minutes, much higher than the 4.5 minutes flight powered by commercial LIBs.
- YR4: Developed a cost-effective high-power Al-air battery cathode that potentially reduce AAB cost by 1500 times.
- YR4: Produced a prototype wireless charging module that can be added to pre-existing robots to add the ability for wireless charging.

Impact & Benefits:

- The potential of significantly improving agricultural drone operational efficiency by extending its flight duration
- The potential for robots currently in use around IoT4Ag to be retrofitted to allow for autonomy via wireless charging.



Project Title: 16_AG COMM: Communication to Enable Agricultural Sensing

Thrust(s): Thrust 2

Faculty Investigators: David Love, Jim Krogmeier, Dennis Buckmaster (Purdue), Bill Eisenstadt (UF)

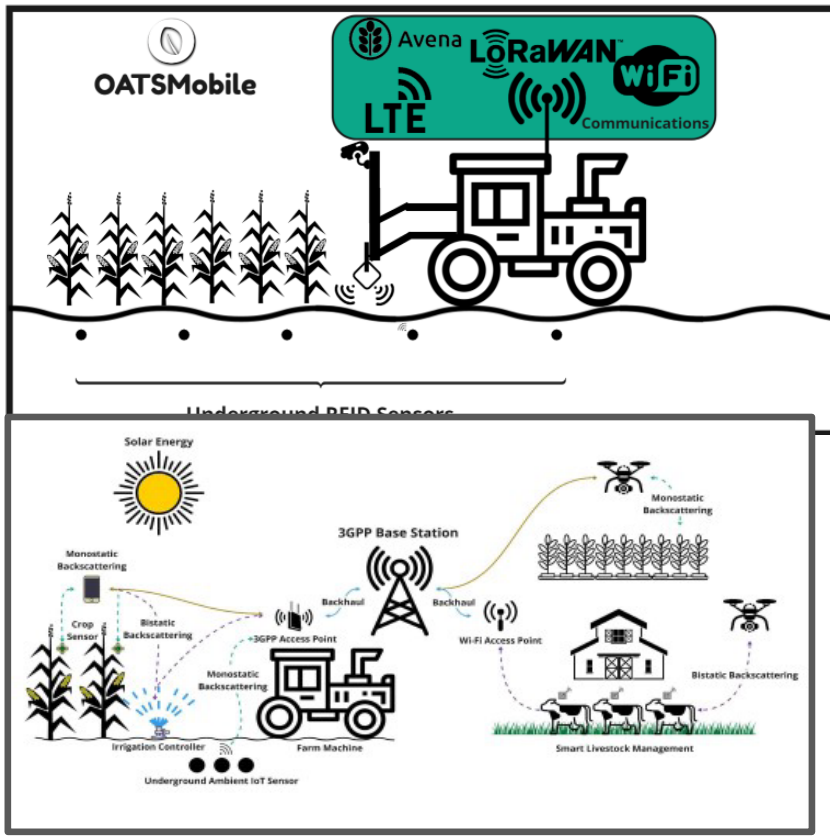


Outcome / Accomplishments (last three years):

- YR3: Developed and analyzed low-latency relaying networks for backhaul communication
- YR3: Designed novel precoders for in-band full duplex relaying
- YR3: Developed an agricultural vehicle, OATSMobile , that can collect and process data in the farmlands, enabled by our communication platforms, Avena and ISOBlue
- YR4: Extensively studied the wireless propagation in rural areas that helps in modelling the wireless channel
- YR4: Analysis of non-terrestrial networks for backhaul communication
- YR4: Developed signal processing algorithms for agricultural sensing using communication infrastructure
- YR4: Developed a LPWAN scheme that aids multi-cell architecture for agricultural sensing

Impact & Benefits:

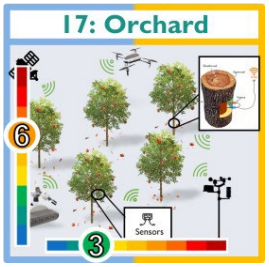
- Our implementations such as OATSMobile , Avena , underground RFID, and ISOBlue (project 7) have been seamlessly integrated to support sophisticated in-field experiments
- Our works on multi-hop relay and integrated sensing and communication aims to steer the direction of 6G for agricultural use cases
- Our work on Ambient IoT aims to steer battery-less sensing and communication in 6G for agricultural use cases.



Project Title: 17_ORCHARD: Developing Technology for Detecting Tree-Specific Water Stress in an Orchard

Thrust(s): Thrust 1 / Thrust 3

Faculty Investigators: Reza Ehsani, Stefano Carpin (UC Merced)



IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

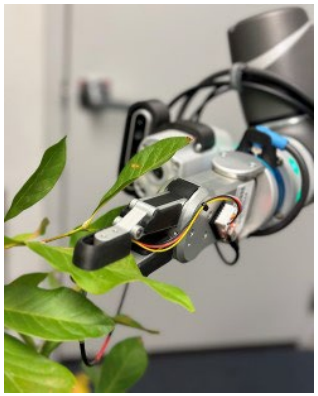
Outcome / Accomplishments :

- YR1: Test site in Merced was equipped with sensors and internet coverage. preliminarily data was collected.
- YR2 - YR3: a large amount of field data including stem water potential, aerial multiband images, sap flow, weather data were collected from two sites
- YR3 - YR4: Developed ML models predicting tree water status with 90% classification accuracy
- YR4: A prototype of a sensor (Water Stress Sensor Clip) for measuring the water content of leaves was developed and evaluated at the test site.
- YR4: A new robotic system capable of measuring hyperspectral data in the visible and NIR ranges has been developed to collect leaf-level spectral data.

Impact & Benefits:

- The ML-based model can utilize easily collectible input data to accurately predict tree-specific stem water potential in orchards, with potential applications to other important tree crops in California.
- The Water Stress Sensor Clip provides an easy-to-use and quick method for determining plant water stress levels. This tool can assist small to medium-sized growers in optimizing irrigation timing and potentially reducing water usage in California.
- The robotic system can automate the labor-intensive process of collecting leaf-level spectral data with the potential for biotic stress detection.



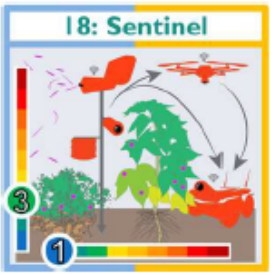




Project Title: 18_SENTINEL: Sensor-based field scouting and plant health monitoring system

Thrust(s): Thrusts 1 / Thrust 3

Faculty Investigators: Ian Small, David Arnold, William Eisenstadt, Alina Zare (UF), Cherie Kagan (Penn), Dave Cappelleri (Purdue)



Outcome / Accomplishments (last three years):

- YR3 – YR4: Trained cotton disease AI-image detection models and automated training workflows for use on the stationary sentinel and other edge computers in the field.
- YR4: Submitted a provisional patent application for an autonomous agricultural drone port for mobile remote monitoring.
- YR4: Demonstrated a waterproof, field-testable stationary sentinel for observing crops and the field environment with 3D AI-imaging, LoRaWAN, WiFi and solar power.
- YR4: The manuscript "Sensor-Based Quantification of Peanut Disease Defoliation Using an Unmanned Aircraft System and Multispectral Imagery" was published (https://apsjournals.apsnet.org/doi/10.1094/PDIS-05-23-0847-RE).
- YR4 Multiple instance regression models using the MI-ClusterRegress algorithm were trained on point spectra obtained from cotton nitrogen trial plants.

Impact & Benefits:

This project is developing integrated systems using proximal and remote sensing to monitor plant health and development and to detect the symptoms and causal agents of abiotic disorders and biotic diseases. Monitoring sensors and AI detection models are being utilized or developed to augment or improve the efficiency of conventional data collection for crop models and decision support systems in project 32. This information will be used to inform and optimize precision crop management.

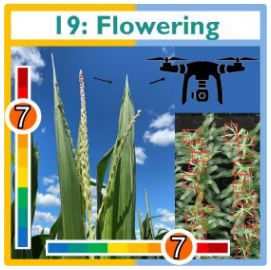


Figure 1. Agricultural drone port system with microdrone for beyond visual line of sight (BVLOS) and mobile proximal imagery data collection. The microdrone shown here is included as an example. This system will function as a basestation for autonomous remote monitoring.

Project Title: 19_FLOWERING: Monitoring Flowering of Row Crops via High-Resolution Remote Sensing Platforms

Thrust(s): Thrust 3 / Thrust 1

Faculty Investigators: Melba Crawford, David Cappelleri (Purdue)



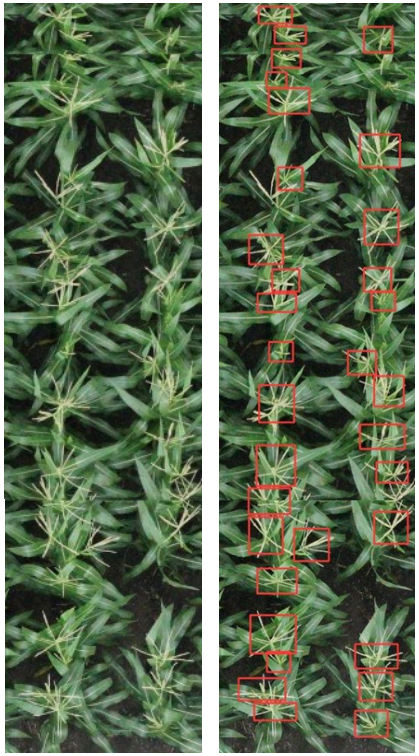
Outcome / Accomplishments

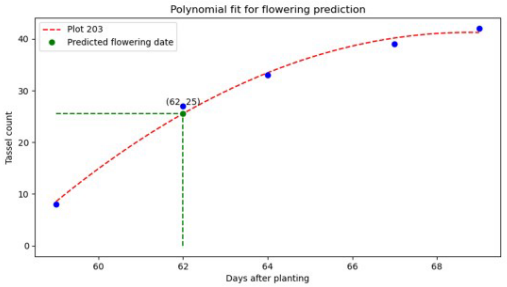
- YR3: Developed robust neural network to detect and monitor flowering through multi-temporal high resolution RGB imaging of tassels from UAVs
  - W. Liu, K. Quijano, and M. Crawford, "YOLOv5-tassel: Detecting Tassels in RGB UAV Imagery with Improved YOLOv5 Based on Transfer Learning," *IEEE J. Selected Topics in Applied Earth Observations and Remote Sensing*, 15, 8085, 2022 (201 citations).
- YR4: Demonstrated capability few shot learning capability of algorithm for near range, non-vertical unorthorectified images based on few-shot learning.

Impact & Benefits:

- Increases reliability and reduces field effort to determine flowering time in both plant breeding and management practice experiments
- Demonstrates that initial models developed using extensive experimental data can be readily updated with limited reference data acquired by other platforms, even if the imagery cannot be orthorectified.



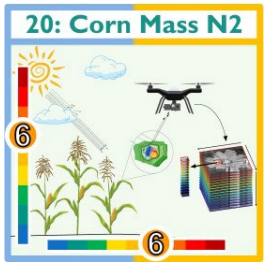




Project Title: 20_CORN MASS N2:Corn Phenology, Biomass and Nitrogen Efficiency Prediction from Integrated Sensors

Thrust(s): Thrust 1 / Thrust 3

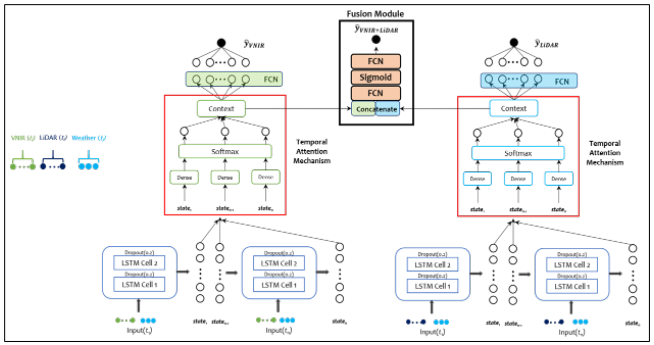
Faculty Investigators: Tony Vyn, Dan Quinn, Melba Crawford (Purdue)

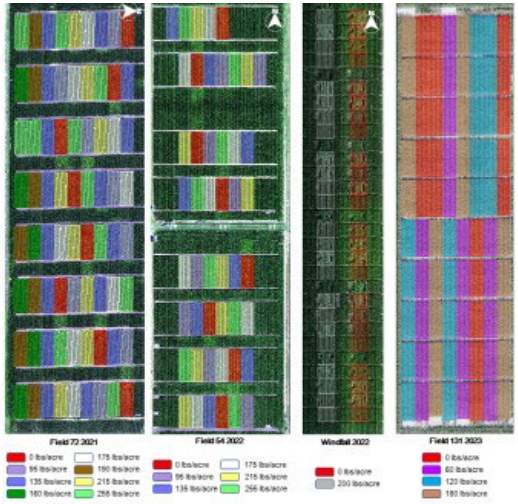


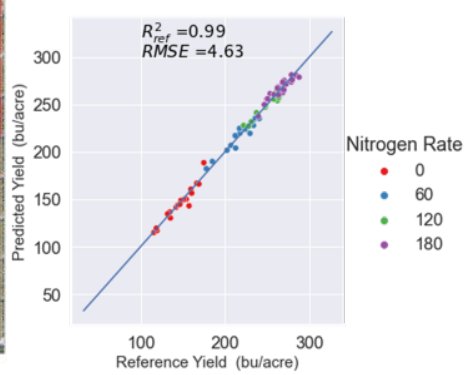
Outcome / Accomplishments :

- YR1 – YR4: Acquired and analyzed multi-date field reference and UAV remote sensing data for multiple nitrogen trials in different geographic locations.
- YR2 – YR4: Three peer reviewed conference papers; four journal publications.
- YR3 – YR4 : Developed LSTM neural networks with temporal attention mechanisms to predict end-of-year maize grain yield based on remote sensing inputs, weather, nitrogen management practices, and plant varieties. Models were extended to other geographic locations via transfer learning.









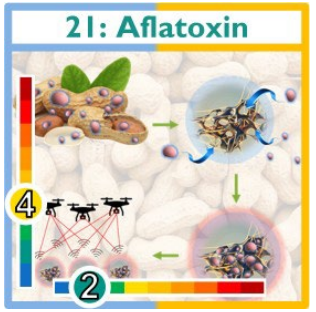
Impact & Benefits:

- Provides capability for agronomists and farms of the future to assess the impact of multi-variety planting and multi-temporal, spatially variable nitrogen management strategies on yield, while reducing costly manual sampling.
- Provides new analytical tools for precision agriculture to detect and monitor nutrient stress and enhance nutrient efficiencies.

Project Title: 21_AFLATOXIN: Assessing Aflatoxin Risk Points in Peanuts

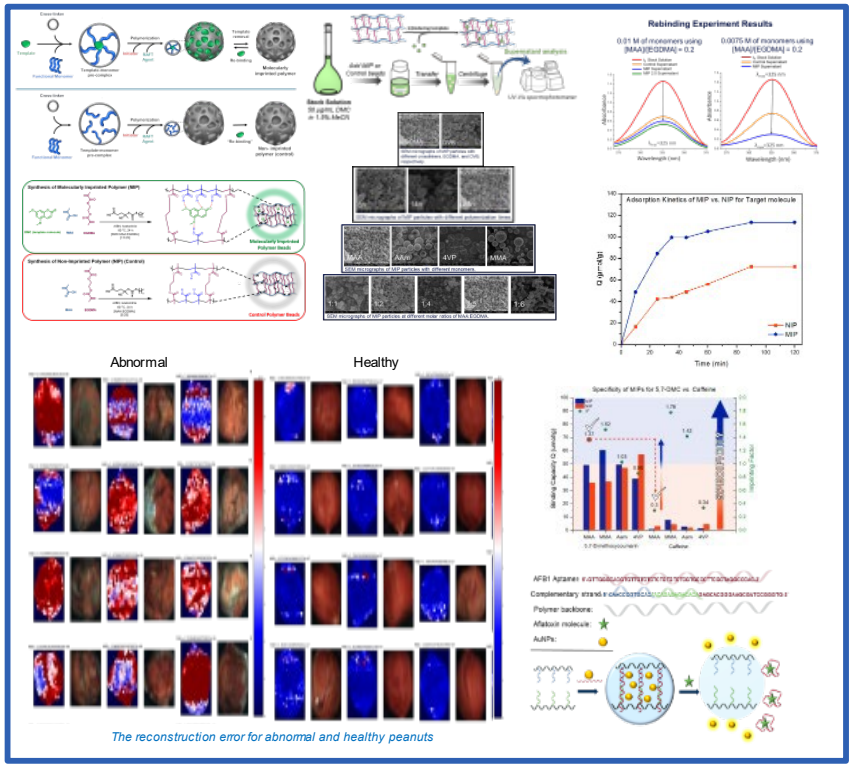
Thrust(s): Thrust 1 / Thrust 3

Faculty Investigators: Brent Sumerlin, Alina Zare (UF), Cherie Kagan (Penn)



Outcome / Accomplishments (last three years):

- YR1: Initiated fabrication of molecularly imprinted polymer (MIP) films but encountered brittleness that hindered embedding into hydrogels and further application with the Leafsense project and plasmonic lattice array nanostructures.
- YR2: Overcame brittleness by utilizing MIP beads instead of films. Successfully synthesized MIP beads using DMC as the template molecule, along with methacrylic acid (MAA) and ethylene glycol dimethacrylate (EGDMA) as monomers through precipitation polymerization. Removed the template to create cavities within the MIPs and characterized the synthesized MIPs for effective rebinding capability. Additionally, successfully estimated peanut maturity as a risk factor for aflatoxin using hyperspectral images of peanut pods.
- YR3: Optimized MIP synthesis by exploring new compositions, including monomers, crosslinkers, and polymerization time, which allowed for visualization of particle morphology by utilizing SEM imaging, determination of system efficiency and specificity. MIPs were determined to have 3x efficacy of non-imprinted polymers (NIPs). Additionally, polymer with methacrylic acid demonstrated high binding capacity (Q = 49.14 µmol/g), imprinting factor (IF = 1.37) and the highest specificity. Simultaneously, initiated aptamer research to provide a visual detection method through color change, enhancing hyperspectral imaging capabilities. In parallel, an autoencoder was developed to detect abnormal and healthy peanut seeds. Optimizing the autoencoder to have a small number of parameters. Higher reconstruction errors were observed with abnormal peanuts which detects abnormal peanuts.



The reconstruction error for abnormal and healthy peanuts

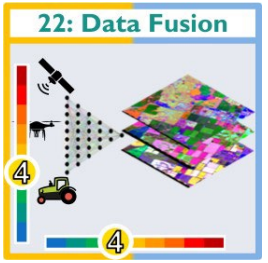
Impact & Benefits:

- Development of MIPs for aflatoxin detection enhances the accuracy and reliability of identifying contamination in crops. Ensuring that aflatoxin levels are detected early, helping farmers take timely actions to mitigate the spread of this mycotoxin, leading to improved crop quality, reduced losses, and increased profitability for farmers.
- MIPs and aptamers offer a cost-effective and chemically stable method for aflatoxin detection. These sensors can be easily embedded into existing agricultural monitoring systems, providing a scalable solution for widespread use.
- The detection of abnormal peanuts seeds helps in identifying risk factors that may lead to aflatoxin with the use of hyperspectral data. This development can help farmers or industry in identifying peanuts that are considered a health hazard.

Project Title: 22_DATA FUSION: Multi-Resolution Raster Data Collection

Thrust(s): Thrust 3 / Thrust 1

Faculty Investigators: Erin Hestir, Reza Ehsani, Stefano Carpin (UC Merced), Melba Crawford (Purdue), Alina Zare (UF)



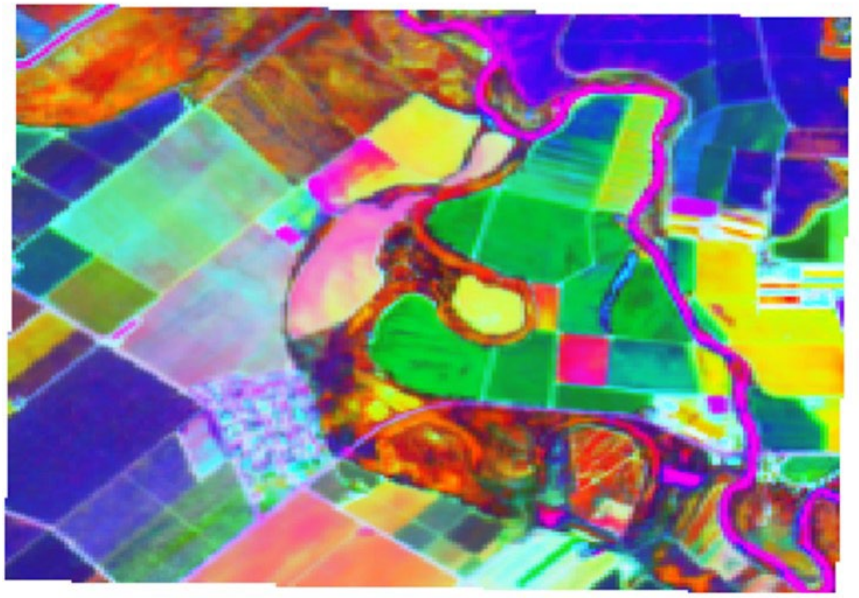
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Outcome / Accomplishments (last three years):

- YR3: Integrated UAV-based data with satellite data, allowing estimation of vegetation fractional cover with high spatial and temporal resolution.
- YR4: Extended work to detect drought stress in row crop and orchard crop cases with high accuracy.
- YR4: Demonstrated the utility of satellite data as an IoT4Ag data source.

Impact & Benefits:

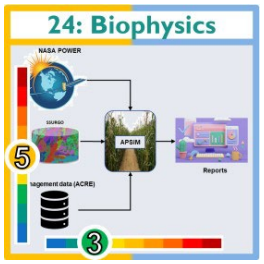
- Improves precision mapping for the application of irrigation, and in the future fertilizers, and pesticides.
- Reduces labor, travel, and the overheads associated with high-frequency UAV acquisitions.
- Commercial, high resolution satellite data has been demonstrated as a viable data source for the sector
- Utilizing free, open-access satellite data has also lowered costs and democratized mapping goals, making the technology accessible to a broader group of end users.



Project Title: 24_BIOPHYSICS: Biophysical Model Enablement

Thrust(s): Thrust 3 / Thrust 1

Faculty Investigators: Dennis Buckmaster, James Krogmeier, Dan Quinn (Purdue)



Outcome / Accomplishments (last three years):

- YR3: Created back-end algorithm, which uses location specific soil, weather, and management data to simulate the corn production using APSIM to help in making informed in-season nitrogen management decisions.
- YR3 / YR4: a portion of this work in ACS (invited speaker), ASABE, and ICPA conference and won presentation excellence award (ASABE).
- YR4: Conducted user-interface design workshop to create user-friendly front- end for decision-support tool (OPTICORN), to increase stakeholder adoption

Impact & Benefits:

- **Improving stem workforce**: Developing OPTICORN for nitrogen fertilizer management empowers extension educators to promote of sustainable agricultural practices to a broader audience
- **Increasing public engagement**: Autonomous robots can apply fertilizer at critical growth stages, which can be estimated by OPTICORN. In alignment with this technological advancement, a startup called Upside Robotics has initiated collaboration efforts.
- **Societal well-being**: The research highlights the need for following sustainable agricultural practices by acknowledging the energy-intensive nitrogen fertilizer production and its implications for greenhouse gas emissions to benefit society.
- **Enhancing infrastructure** The OPTICORN tool enables breeders to assess cultivar performance under varying environmental conditions, facilitating informed decision-making about genetics and improving crop resilience.



Figure 1: Flowchart of overall approach illustrating different stages and processes of user-interface designing, starting with gallery walk and voting method, to user-interface creation, and followed by final agreed version

Project Title: 27_DATA INTEGRATION: Data Interoperability and Integration

Thrust(s): Thrust 3 / Thrust 2

Faculty Investigators: Dennis Buckmaster, Jim Krogmeier (Purdue)



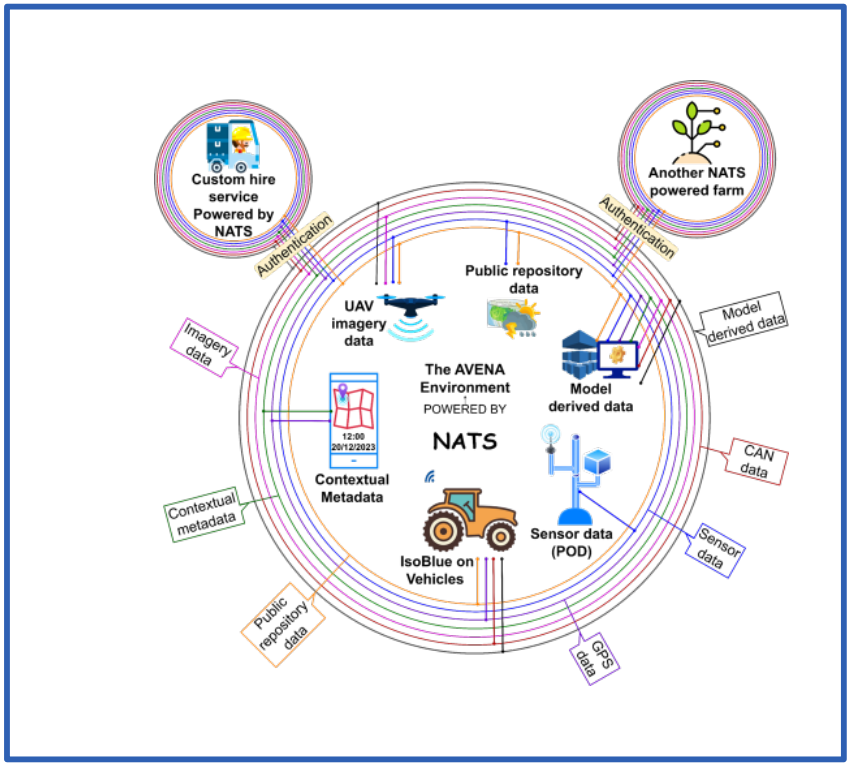
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Outcome / Accomplishments (last three years):

- YR3: Development of contextual meta app, Meta Ag
- YR4: Integration schema of contextual metadata into IoT streams
- YR4: Integration of public repository data (weather and SSURGO soil characteristics) in Avena framework (IoT stream via NATS)

Impact & Benefits:

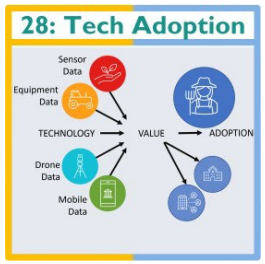
- Contextual metadata collection was made automatic and digital which makes the operational recordkeeping less erroneous and complete
- Integration of data from diverse sources and of varied granularity were integrated to facilitate interoperability in real-time scopes



Project Title: 28_TECH ADOPTION: Barriers to Adopting IoT4Ag Technology: Mixed Methods Research Study

Thrust(s): Thrust 3 / Thrust 1

Faculty Investigators: Catherine Keske, Lisa Yeo (UC Merced), Kathryn Stofer, Sebastian Galindo (UF)



Outcome / Accomplishments :

YR1 - YR4: Removing barriers

- Identified several pathways forward for technology adoption
- Enriched our understanding of how data generates value for decision - making and guiding future research directions.

YR3 – YR4: Community Engagement

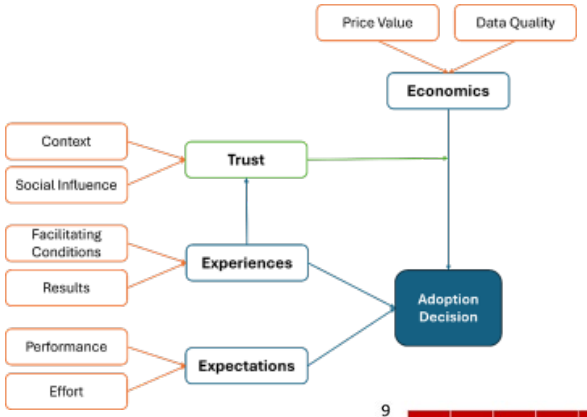
- Created a comprehensive map showing interested communities and their needs.

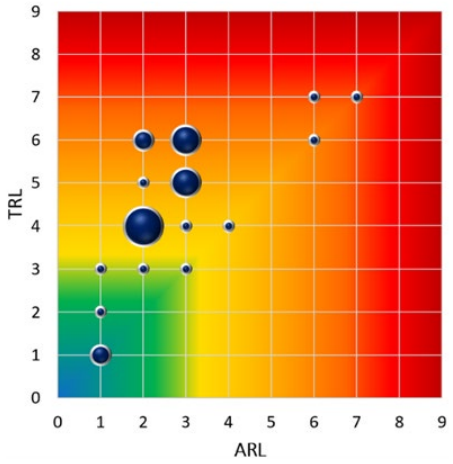
YR4: Assessing Technology Readiness

- Developed a matrix combining traditional technology readiness levels with a new end-user adoption readiness scale.

YR4: Knowledge Dissemination

- Two papers in review at academic journals
- One peer-reviewed conference presentation and multiple posters





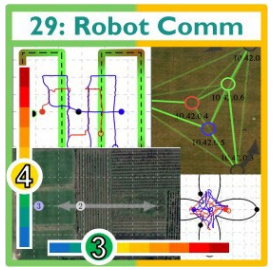
Impact & Benefits:

- Guidance for industry and policy makers for increasing technology adoption and diffusion
- Assessment tool to help scientists and engineers move their new technology out of the lab
- A pathway to strengthen community -developer ties, optimizing strategies for new technology development and diffusion.

Project Title: 29_ROBOT COMM: Deployment of Autonomous Ground Robots to Facilitate Communication

Thrust(s): Thrust 2 / Thrust 1

Faculty Investigators: Alejandro Ribeiro, Vijay Kumar (Penn), Dave Cappelleri (Purdue), Stefano Carpin (UC Merced)



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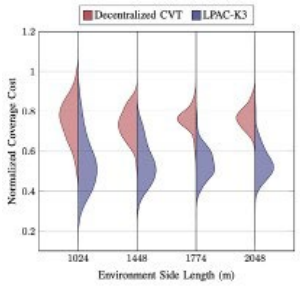
Outcome / Accomplishments (last three years):

- YR4: TRL4. Demonstrated LPAC, a fully decentralized swarm model that scales with environment and team size.
- YR4: LPAC performs significantly better than baseline centralized and decentralized algorithms on coverage problems.

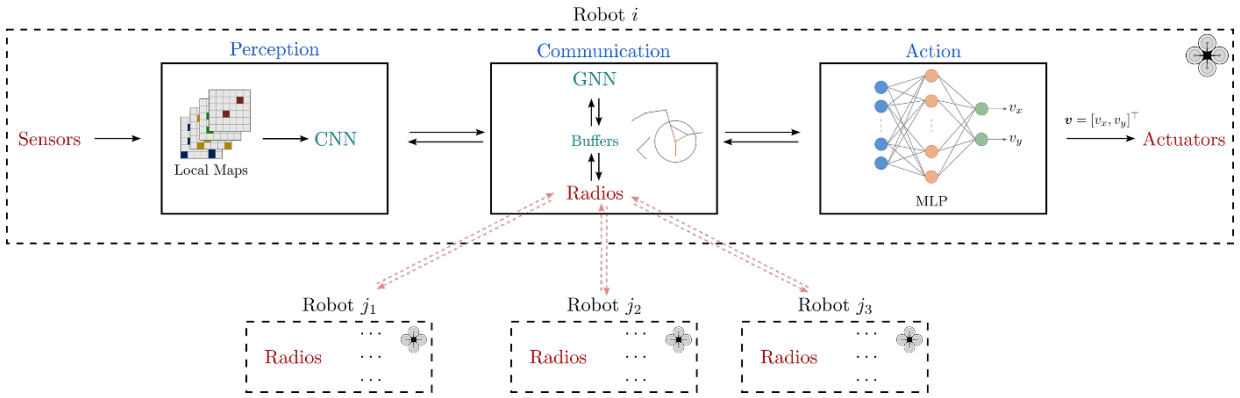
Impact & Benefits:

- Enables the deployment of robot swarms without centralized infrastructure.
- Agricultural tasks such as crop health monitoring and livestock tracking are readily modeled as coverage problems.

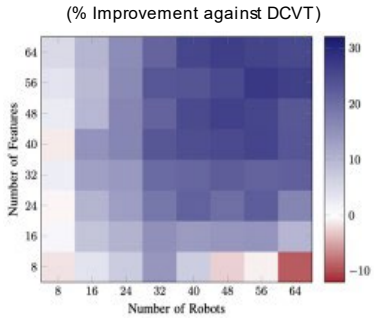
Environment Size



LPAC Model



Team Size



Project Title: 32_SPRAY SYS: Improving the Efficiency of Crop Input Applications Using Advanced Spray

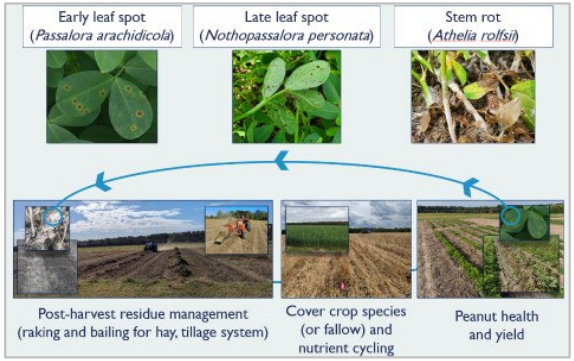
Thrust(s): Thrust 1 / Thrust 3

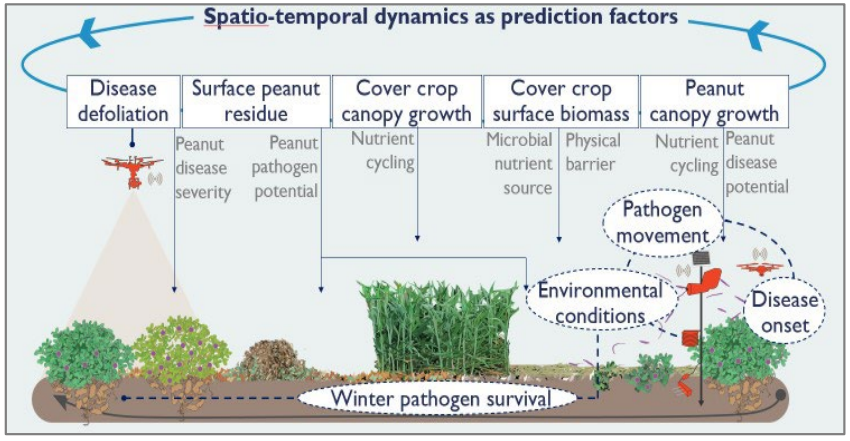
Faculty Investigators: Ian Small, William Eisenstadt, Alina Zare (UF)



Outcome / Accomplishments (last three years):

- YR1 – YR4: Peanut field trials at the UF/IFAS NFREC in Quincy and Live Oak have been designed and are being conducted to evaluate winter field management practices, in-field environmental sensor data, and multispectral drone imagery as predictive inputs for pathogen activity, disease development, and plant health.
- YR4: Publications in peanut disease modeling including the following:
  - Sanjel, S., Colee, J., Barocco, R., Dufault, N.S., Tillman, B., Punja, Z. K., Seepaul, R., Small, I.M. 2023. Environmental factors influencing stem rot development in peanut: predictors and action thresholds for disease management. Phytopathology 114 (2) 393 -404. https://doi.org/10.1094/PHYTO-05-23-0164-R
  - Sanjel, S., Guerra, V., Seepaul, R., Mackowiak, C., Punja, Z.K., Dufault, N.S., Tillman, B., Bradford, K.J., Small, I.M. 2023. Application of hydrothermal time models to predict sclerotial germination of *Athelia rolfsii*. Phytopathology 114 (1) 126-136 https://doi.org/10.1094/PHYTO-04-23-0132-R





Impact & Benefits:

- The objective is to develop prediction models and decision support tools using an integrated system of sensors to inform the precision management of peanut health and diseases.
- Peanut fungal diseases caused by pathogens that survive within fields between seasons are known to cause economic yield loss if not managed. Optimizing crop protection inputs is of great value to peanut growers.

Project Title: 33_NUTRIENT MANAGEMENT: A new Paradigm for Nutrient Management in the US Enabled by Sensing, IoT, and Prediction Modeling

Thrust(s): Thrust 3 / Thrust 1

Faculty Investigators: Charlie Messina (UF), Melba Crawford (Purdue)



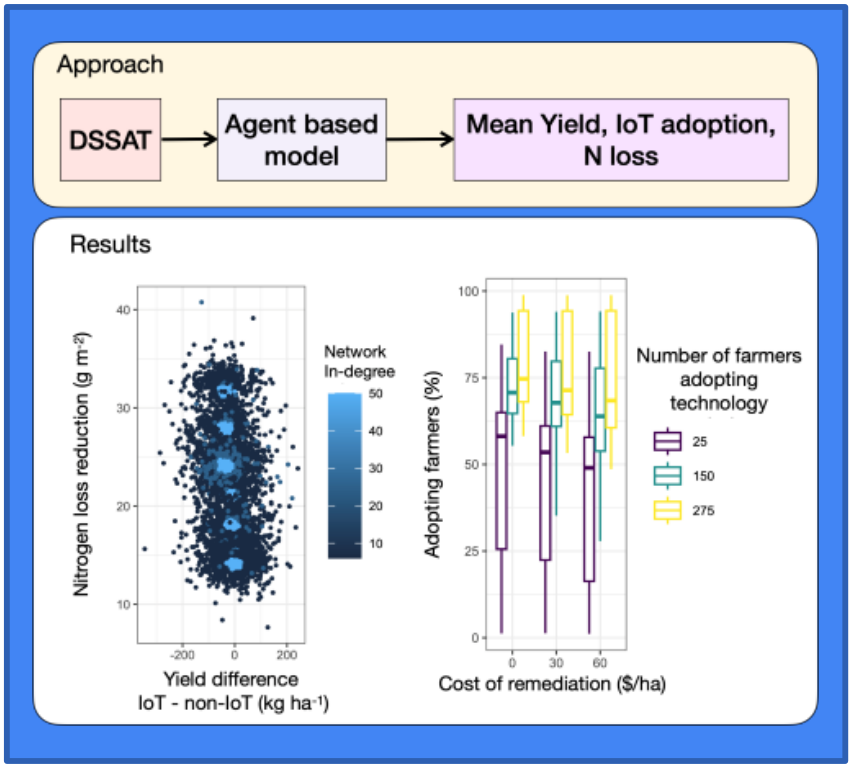
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Outcome / Accomplishments (last three years):

- YR2: DSSAT models implemented in HiperGator
- YR3: Study demonstrating the framework completed
- YR3: Transition project from TRL1 to TRL 3
- YR4: SWAT fused with Deep Learning improve simulation of soil water in the landscape (r^2=0.36 to r^2=0.52)

Impact & Benefits:

- Using IoT it is feasible to reduce N use (up to 50%) and N loss (up to 30 g m^{-2}) in maize production with minimum yield loss and increased profitability (25$/ha)
- Social network is a key determinant of technology adoption
- Remediation costs is not a major deterrent of technology adoption
- Improved SWAT-DL can enable improved deployment of sensors in the landscape, and thus reduce the use of water and nutrient resources



Project Title: 34_STAKEHOLDER ENGAGEMENT: Community Engagement for IoT4Ag NSF Engineering Research Center
Thrust(s): EWD, DCI, and IE
Faculty Investigators: Kathryn Stofer (UF), Sebastian Galindo (UF)



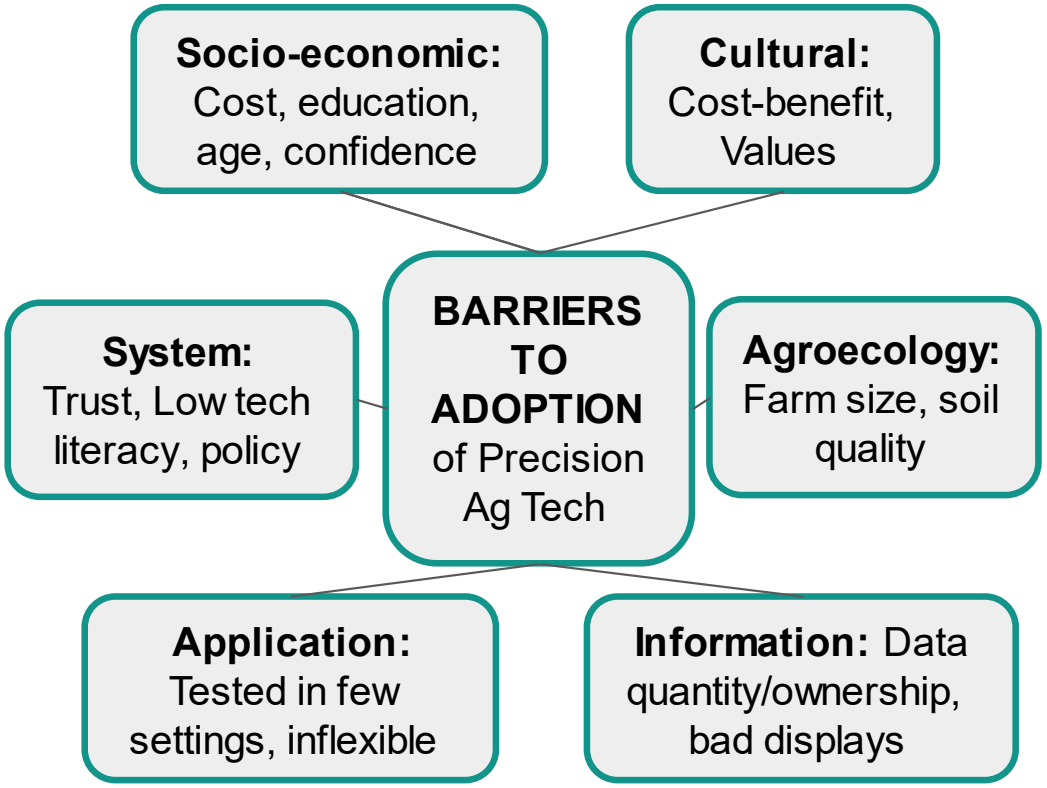
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Outcome / Accomplishments :

- YR3 - YR4: Building relationships with farmer broker groups.
- YR3 - YR4: Webinars and tabling for external audiences, workshops and publications for internal audiences.
- YR3 - YR4: Established collaboration around farmer engagement with Project 28: Tech Adoption including conceptualizing Adoption Readiness Levels.
- YR3 - YR4: Literature review on barriers to precision agriculture adoption.

Impact & Benefits:

- Developed initial plan to identify and support key leaders for long-term farmer engagement for diffusion of technology adoption
- Increases in internal engagement capacity for IoT4Ag members
- Technologies and professional development activities are increasingly aligned with farmer needs



IoT4Ag Annual Meeting
University of California, Merced (June 2024)

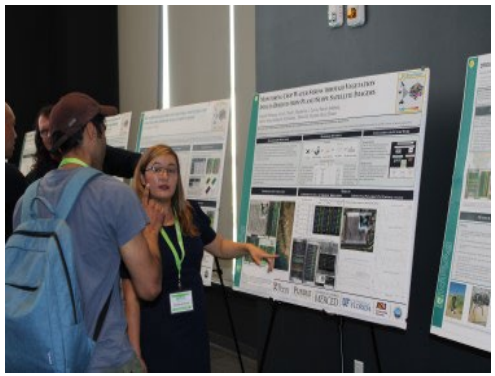
Annual Meeting: Poster Competition, Professional Development Workshops, Technology Demos, and more.
Research / Workforce Development / Diversity & Culture of Inclusion / Innovation Ecosystem

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Year 4 Accomplishments:

- The Annual Meeting, held at the University of California, Merced, was attended by over 120 participants, including faculty, students, staff, advisory board members, industry representatives, and invited guests.
- The retreat began with an opening reception, poster session and speech from our keynote speaker Shely Aronov, Founder & CEO of InnerPlant about building a successful business model beyond just developing good technologies .
- More than 40 students and postdocs presented 41 posters covering a range of IoT4Ag projects were showcased, and with the upcoming NSF ERC Biennial, 6 graduate students competed in a Perfect Pitch competition, with Marcos Zuzuarregui from UC Merced winning the competition .
- Professional development opportunities like a student career panel, community college engagement, entrepreneurship start-ups, and tours of local farm and UC Merced testbeds.



Project Impact & Benefits: The Annual Meeting gave the new and old Center members an opportunity to meet each other and make connections and conversations to create a sense of community offline. Attendees learned new skills, explored agricultural facilities, heard from agricultural industries about challenges facing crop production, engaged in team-building activities and volunteer service, and learn more about the goals and achievements of the center.

MANRRS Conference 2024 - Chicago, IL

Workforce Development / Diversity & Culture of Inclusion
Leaders: Sue Ann Bidstrup-Allen, Paulo Arratia, Kristin Field (Penn)

Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS)

- IoT4Ag hosted a booth at the MANRRS 2024 career fair where we spoke to students, academic professionals and industry members about the mission, research and opportunities of the center.

- IoT4Ag graduate students and postdoctoral fellow organized and facilitated a coding and robotics workshop for more than 267 high school students as part of Junior MANRRS Symposium.



Pathway to Ph.D. Program (PPP)

Program to Introduce Underserved Students to Graduate School Applications and Fellowships

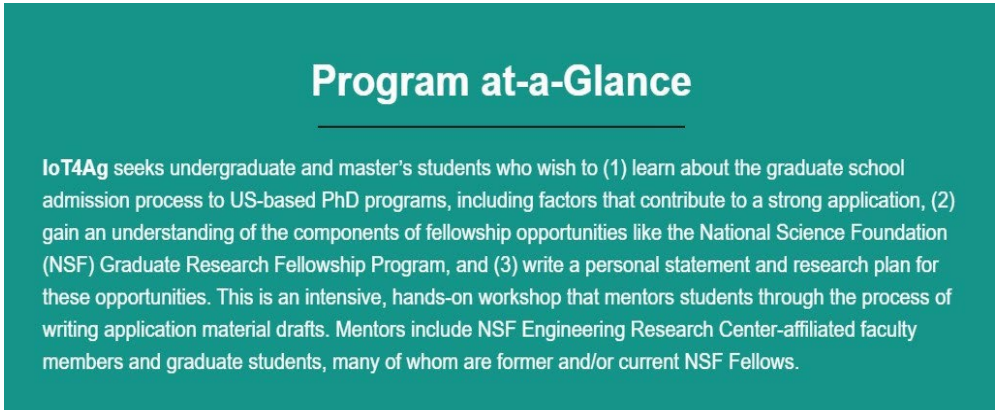
Diversity & Culture of Inclusion

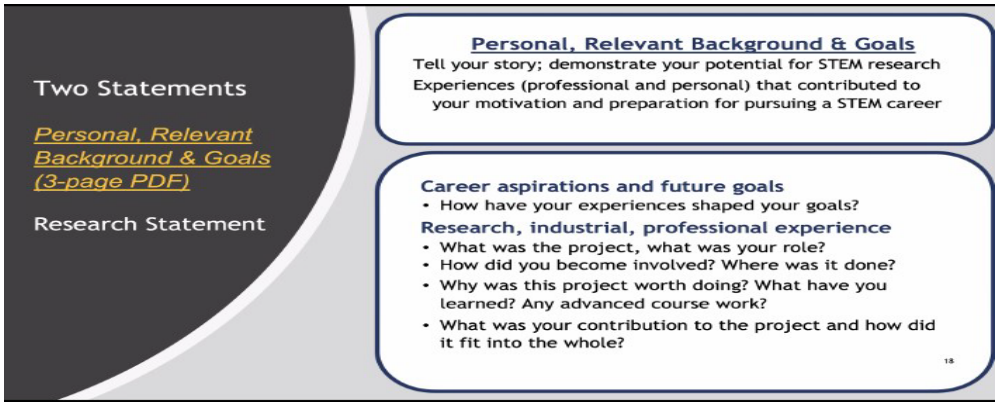
Co-Leaders: Paulo Arratia, Kristin Field (Penn), Lisa Yeo (Merced)

Year 4 Accomplishments:

- Hosted the second annual PPP virtually on September 9th, 2023, with 99 undergraduate applicants (up by 10 from last year), with 42 participants, and 25 graduate mentors, up by 10 graduate mentors from last year.
- PPP mentees submitted graduate applications to a range of universities.
- Initial program feedback indicated that all participants thought that the PPP was useful.
- The 2024 Pathways to Ph.D. Program occurred on September 14, 2024, in Year 5.
- Recruitment activities occurred at Hispanic Serving Institutions and Historically Black Colleges and Universities, and special events focused on women in STEM.

Project Impact & Benefits: PPP was created to address the lack of awareness by underrepresented minority (URM) and first-generation low-income (FGLI) students about the graduate school admission process and funding opportunities. Additionally, undergraduate students were matched with a mentor to review components of fellowship applications and graduate school materials. The PPP program serves as a avenue to recruit diverse students to IoT4Ag educational opportunities and the broader STEM community.





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Appendix VI. List of ERC Projects

Below are the YR4 projects, listed by primary thrust, though most of the projects cross thrusts as noted below. This project list includes the project ID number with the full project title and the lead faculty investigator name and the faculty co-investigator name(s), with the institution affiliation in parenthesis by the faculty member's name.

Project ID	Project Details	Secondary Thrust
Thrust 1		
1_LEAFSENSE	**Full Title:** Leaf Moisture and Temperature Sensors **Lead PI:** Cherie Kagan (Penn)	
2_OPTICAL ZOOM	**Full Title:** Sensor and Detector **Lead PI:** Sanjeev Koppal (Florida)	Thrust 3
3_SUBSURFACE SENSE	**Full Title:** Passive, Sub-surface Biodegradable Sensors and Components **Lead PI:** Troy Olsson (Penn)	Thrust 2
8_AGBOT	**Full Title:** AgBot: Crop-Sampling Unmanned Ground Vehicle (UGV) **Lead PI:** Dave Cappelleri (Purdue)	Thrust 2
9_SEMANTIC MAPPING	**Full Title:** Semantic Mapping of Orchards for Yield Estimation **Lead PI:** Vijay Kumar (Penn)	Thrust 3
10_PATH PLANNING	**Full Title:** Informed Path Planning for Data Collection in Orchards **Lead PI:** Stefano Carpin (UC Merced)	Thrust 3
17_ORCHARD	**Full Title:** Developing Technology for Detecting Tree-Specific Water Stress in an Orchard **Lead PI:** Reza Eshani (UC Merced)	Thrust 3

Project ID	Project Details	Secondary Thrust
18_SENTINEL	**Full Title:** Sensor-based field scouting and plant health monitoring system **Lead PI:** Ian Small (Florida)	Thrust 3
20_CORN MASS N2	**Full Title:** Corn Phenology, Biomass and Nitrogen Efficiency prediction from Integrated Sensors **Lead PI:** Melba Crawford (Purdue)	Thrust 3
21_AFLATOXIN	**Full Title:** Assessing Aflatoxin Risk Points in Peanuts **Lead PI:** Brent Sumerlin (Florida)	Thrust 3
32_SPRAY SYS	**Full Title:** Improving the Efficiency of Crop Input Applications Using Smart Applications Systems **Lead PI:** Ian Small (Florida)	Thrust 3
Thrust 2		
4_AIR BATTERIES	**Full Title:** Biodegradable Air Batteries for Distributed Sensing **Lead PI:** Mark Allen (Penn)	Thrust 1
7_EDGE COMP-COMM	**Full Title:** Edge Computing and Communication for Agricultural Sensors **Lead PI:** Jim Krogmeier (Purdue)	
11_CLUTTERED ENVIRONMENTS	**Full Title:** Wireless Charging of Electronics in Cluttered Environments **Lead PI:** David Arnold (Florida)	
12_ROBOT POWER	**Full Title:** Autonomous Wireless Charging of Drones **Lead PI:** Sue Ann Bidstrup Allen (Penn)	Thrust 1
16_AG COMM	**Full Title:** Communication to Enable Agricultural Sensing **Lead PI:** David Love (Purdue)	

Project ID	Project Details	Secondary Thrust
29_ROBOT COMM	**Full Title:** Deployment of Autonomous Ground Robots to Facilitate Communication **Lead PI:** Alejandro Ribiero (Penn)	Thrust 3
Thrust 3		
19_FLOWERING	**Full Title:** Monitoring Flowering of Row Crops via High Resolution Remote Sensing Platforms **Lead PI:** Melba Crawford (Purdue)	Thrust 1
22_DATA FUSION	**Full Title:** Multi-Resolution Raster Data Collection **Lead PI:** Erin Hestir (UC Merced)	Thrust 1
24_BIOPHYSICS	**Full Title:** Biophysical model enablement **Lead PI:** Dennis Buckmaster (Purdue)	Thrust 1
27_DATA INTEGRATION	**Full Title:** Data interoperability and integration **Lead PI:** Dennis Buckmaster (Purdue)	Thrust 2
28_TECH ADOPTION	**Full Title:** Barriers to Adopting IoT4Ag Technology: Mixed Methods Research Study **Lead PI:** Lisa Yeo (UC Merced)	Thrust 1
33_NUTRIENT MANAGEMENT	**Full Title:** A New Paradigm for Nutrient Management in the US Enabled by Sensing, IoT and Prediction Modeling **Lead PI:** Charles Messina (Florida)	Thrust 1
Engineering Workforce Development Diversity & Culture of Inclusion Innovation Ecosystem		
34_STAKEHOLDER ENGAGEMENT	**Full Title:** Community Engagement for Internet of Things for Precision Agriculture (IoT4Ag) NSF Engineering Research Center **Lead PI:** Kathryn Stofer (Florida)	

Associated Projects		
2AP_AG AID (WFD)	**Full Title:** AI Institute for Transforming Workforce & Decision Support **Lead PI:** Reza Ehsani (UC Merced)	Thrust 1
3AP_HSI AG EDUCATION (WFD)	**Full Title:** Integrated education programs to train students for a future in the agricultural and food industry **Lead PI:** Reza Ehsani (UC Merced)	DCI
4AP_FUTURE OF WORK (Thrust 3)	**Full Title:** Elevating Farm Worker-Robot Collaborations in Agri-Food Ecosystems **Lead PI:** Reza Ehsani (UC Merced)	

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 1_LEAFSENSE: Leaf Moisture and Temperature Sensors
Thrust(s): 1_Agricultural Sensor Systems
Lead Faculty Investigator: Cherie Kagan (Penn)
Co-Investigator(s): Kevin Turner, Paulo Arratia (Penn), Reza Ehsani (UC Merced), Ian Small, Tony Vyn (UF)
Researcher(s): Lawrence, Cai, Kramadhati, Boyd, Iyer, Pradeep (PhD/Penn), Mallavarapu (Postdoc/Penn), Lu (MS.Penn) Mohamed (Undergrad/Penn), Toudeshki (Staff/Merced), Barocco (PhD/UF), Zhang (Undergrad/Penn), Huang, Holland, Platon (REU/Penn), Turko (RET/Penn)

LOCATION ON 3-PLANE DIAGRAM: 1. Fundamental knowledge / 2. Enabling technology
TRL #: 5 (sensors deployed in field) **ARL #:** 2 (in testbed use by IoT4Ag project team)

OBJECTIVES & CENTER ALIGNMENT: Develop low-cost, biodegradable, and passive sensors for remote sensing of crop conditions at the leaf level to help mitigate crop stress. This supports the Thrust 1 goal of spatially and temporally mapping complex plant and environmental variables. Colorimetric leaf sensors in the visible and NIR based on optical metasurfaces and target-specific adaptive polymers are interrogated by spectrometers and hyperspectral cameras and evaluated by the figure-of-merit (FOM) defined as $Q \times S \times \Delta R$ where Q is the quality factor, S is the sensitivity, and ΔR is the modulation of the resonance. (**Figure 1**)

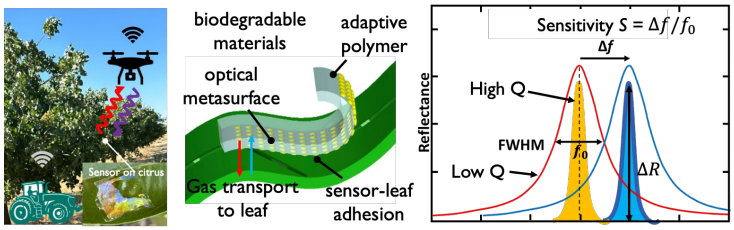


Figure 1: Overview of LEAFSENSE, showing leaf sensors deployed at Merced testbed, a leaf sensor device schematic, and colorimetric sensor FOM parameters. Optical response is probed by cameras described in Project 2_Optical Zoom.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
Over the past three years, we developed a scalable and sustainable nanomanufacturing platform for fabrication of optical metasurfaces via nanoimprinting of low-cost aqueous TiO_2 nanocrystal (NC) inks. We realized a single-step method of achieving high Q resonances in the visible and NIR by tailoring residual layer thicknesses to create optical metasurfaces with waveguides. We filed a patent application (#63/378,980) and produced a peer-reviewed publication in ACS Appl. Nano Mater. 2023, 6, 18, 17294–17300. We also fabricated and tested biodegradable, flexible and adhesive substrates with chitosan and cellulose biopolymers for leaf compatibility.

This year, we deployed moisture-responsive colorimetric sensors on citrus plants by optimizing metasurface fabrication on the leaf-compatible substrates. Leaf level tests of sensors at UF and UC Merced testbeds were used to measure leaf wetness and determine FOM requirements for interrogation of sensors on the leaf in the field. Sensor detectability was improved through (i) increasing Q, by coupling a waveguide layer to patterned pillar structures, (ii) increasing modulation up to 55%, by combining high aspect ratio structures with high refractive index NC

materials (Figure 2a), and (iii) significantly increasing S up to 300%, by exploiting the colloidal nature of our inks and incorporating controlled amounts of adaptive polymer into the TiO_2 NC inks. We discovered that polymer incorporation also allows the refractive index of our devices to be enhanced by ~ 8% (Figure 2c). This approach allows us to create high FOM tunable metasurfaces on responsive substrates, not achievable with conventional bulk processes.

Sensor architectures that distinguish and measure leaf wetness from environmental relative humidity (RH) were validated using PDMS and ethyl cellulose substrates. Sensors are designed to respond to leaf wetness selectively over changes in local leaf humidity by using architectural degrees of freedom such as the sensor orientation. This is achieved by forming a cavity at the leaf surface that contains the metasurface and adaptive polymer backed by an impermeable substrate such that any moisture changes are solely attributed to leaf wetness (Figure 2d). A patent application on sensor architectures for multi-stress sensing using this colorimetric platform was filed (#63/535,810), and multiple sensors were deployed for in-field tests.

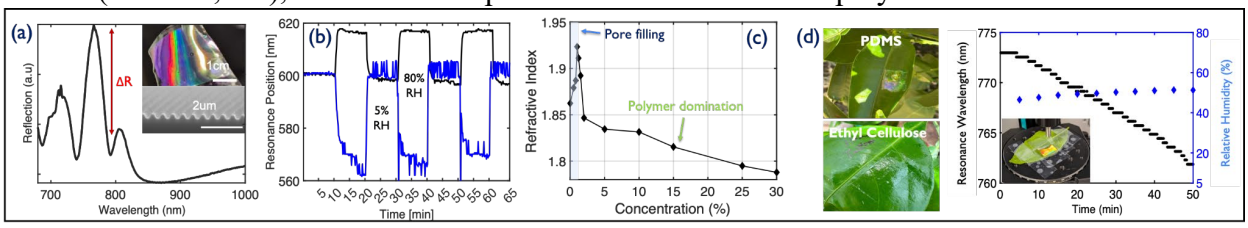


Figure 2: Leaf sensor engineering: (a) Reflectance spectra of high-aspect ratio/high-index NC-based optical metasurfaces on flexible substrates, (b) RH-dependent resonance of Chitosan-TiO_2 NC composite metasurface fabricated on glass (black) and Chitosan (blue) for high sensitivity sensors, (c) Refractive index of chitosan-TiO_2 NC composites, showing enhanced refractive indices at low concentration and enabling NC metasurfaces with high FOM via improvements in S and ΔR, and (d) substrate adhesion to citrus leaves, and tracking of leaf wetness showing an expected spectral shift relative to a nearly constant RH environment.

TESTBED & JOINT-OP ACTIVITY:

This year, we fabricated moisture-sensitive metasurfaces on custom flexible substrates made of different thicknesses of ethyl cellulose and PDMS optimized for both sensor nanoimprinting and leaf adhesion. Sensors transferred to citrus leaves in the lab showed differing rates of moisture permeability based on substrate material and thickness, as measured through porometry of the leaf through the sensor. Differential sensing of leaf wetness and local environmental humidity was realized by changing the metasurface orientation towards and away from the leaf. Abaxial leaf attachment proved to show higher leaf wetness due to the larger numbers of stomates, as benchmarked by porometry measurements.

Sensors were taken to the UC Merced testbed for experiments in a greenhouse and in the field on citrus plants. During a three-day trial, the adhesive sensors attached via stiction and sacrificial layer removal remained on the leaves and images were captured every morning and afternoon to monitor the resonance and document the adhesive conditions. The designed resonance from the sensor could be detected from the noise of the surrounding environment. Hyperspectral imaging of the sensors showed promising results as the cameras were able to locate and measure the sensors remotely (in collaboration with Project 2_Optical Zoom).

Project Title: 1_LEAFSENSE: Leaf Moisture and Temperature Sensors

Thrust(s): Thrust 1 – Agricultural Sensor Systems ARL / TRL: 2/5

Faculty Investigators: Cherie Kagan, Kevin Turner, Paulo Arratia (Penn); Reza Ehsani (Merced), Ian Small, Vyn (UF)

Researcher(s): Lawrence, Cai, Kramadhati, Boyd, Iyer, Pradeep, Mallavarapu, Lu, Mohamed, Zhang (Penn), Toudeshki (UC Merced), Barocco (UF), Huang, Holland, Platon (REU) Turko (RET)

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PROJECT OVERVIEW

Project Goals: To design and test low-cost, biodegradable sensors capable of sensing changes in canopy microclimate to help mitigate crop stress. The sensors are based on optical metasurfaces and designed to exhibit color changes based on leaf target measurands. These sensors will be used to capture the diurnal and stress-induced changes in leaf moisture and temperature, and will be coupled with the development of models that correlate leaf wetness and temperature with the onset of plant diseases and water stress.

Location on 3-Plane Diagram: Fundamental Knowledge, Enabling Technology

Testbeds and Joint Ops: Testbed 2: Integrated Solutions for Precision Farming of Tree Crops at UC Merced. Joint Op 2: Integrated Systems to Optimize Water Use in Tree Crops. Work is ongoing to integrate multispectral cameras on existing farm infrastructure (such as center pivot irrigation systems or tractors) or aerial- or ground-based robots in collaboration with 2_OPTICAL_ZOOM project to image the sensors on the leaves.

SUMMARY FIGURE

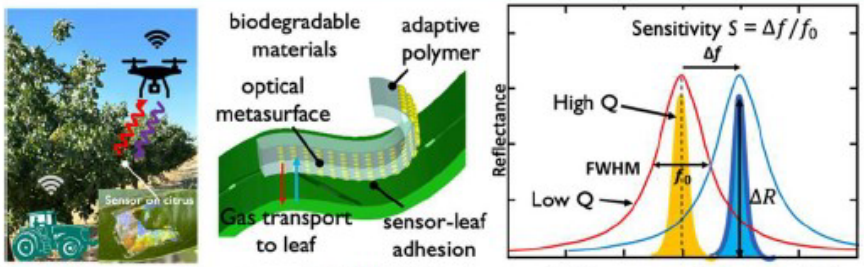


Figure Caption: Overview of LEAFSENSE, showing leaf sensors deployed at Merced testbed, a leaf sensor device schematic, and colorimetric sensor FOM parameters. Optical response is probed by cameras described in Project 2_Optical Zoom

RESEARCH APPROACH & BARRIERS

Approach in Year 4: Colorimetric sensors based on optical metasurfaces are designed to exhibit a high figure of merit (FOM) in the visible and NIR with adaptive polymers that respond to relevant environmental conditions. Novel inks were introduced into the manufacturing process to improve throughput and print fidelity, which increased the quality factor, sensitivity, and resonance modulation of the sensors. Sensors were integrated with adhesive substrates that were optimized for leaf compatibility, and deployed in lab and in field to monitor leaf wetness at the UC Merced Testbed.

Barriers: Leaf transpiration is highly sensitive to various stimuli, such as lighting and the leaf's position on the plant, making data interpretation challenging unless measured under controlled conditions. The relationship between the detectability of the sensors by imaging systems (Project 2_Optical Zoom) and factors like resonance strength, spectral shifts, and sensor size must be understood to allow for system co-design.

KEY ACCOMPLISHMENTS TO-DATE

Accomplishments and Impact: Optimized TiO_2 NC metasurface manufacturing, design, and imprinting for increased quality factor. Increased sensitivities of sensors up to 300% by incorporating adaptive polymers into the metasurface to maximize sensor FOM. Developed and synthesized custom substrates for leaf adhesion and imprintability. Performed leaf level tests in lab, greenhouse, and orchard in collaboration with 2_Optical Zoom with flexible, adhesive moisture-responsive colorimetric sensors to measure leaf wetness.

Year 5 plans: Correlate sensor responses to leaf porometry measurements to understand the relationship between observed spectral shifts and transpiration rates both in the lab and in the field. Analyze sensor figures of merit (FOM) and size requirements for detection by imaging systems. Develop multi-stress sensors to measure leaf moisture and temperature, enabling more accurate measurement of leaf transpiration. Extend the use of current adhesive substrates to other relevant crops, such as almond and pistachio leaves.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 2_OPTICAL ZOOM: Sensor and Detector
Thrust(s): Thrust 1 – Agricultural Sensor Systems / Thrust 3_Agricultural Response Systems
Lead Faculty Investigator: Sanjeev Koppal (Florida)
Co-Investigator(s): Vijay Kumar; Cherie Kagan (Penn), Dave Cappelleri (Purdue)
Researcher(s): Kramadhati, Li, Hopkins, Lawrence (PhD/Penn), Murali, Mallavarapu (Postdoc/Penn), Arnold (PhD/Florida)

LOCATION ON 3-PLANE DIAGRAM: 3. SYSTEMS **TRL:** #5 **ARL #:** #3

OBJECTIVES & CENTER ALIGNMENT:

Remote sensing has been utilized in precision agriculture to image crops and their environments, to monitor crop health and improve yield. Current remote sensing techniques cannot directly measure plant-stress indicators such as environmental humidity, leaf transpiration rate, and the presence of volatile organic compounds and toxins. Low-cost, colorimetric sensors deployed in the field are being developed in Project 1_LeafSense to directly measure environmental and plant conditions that affect crop yield and communicate this information via optical or near-IR signals detectable by current aerial/ground-based imaging systems. The key objectives of this project are to develop and comprehensively evaluate an autonomous robotic imaging platform that can localize and measure colorimetric sensors deployed in the field. This involves a system integration of (1) a ground-vehicle capable of traversing agricultural fields, (2) visual serving controller and algorithms to localize and maneuver towards plants with colorimetric sensors, (3) a colorimetric sensor segmenter to detect and measure the sensor's spectral response with RGB and Hyperspectral cameras respectively.

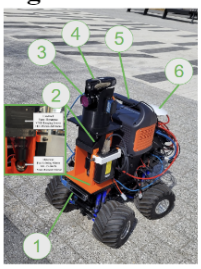
KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

In YR1-YR2 we built/tested discrete components of the system beginning with a FLIR RGB camera mounted on a dolly, a preliminary sensor segmentation algorithm, and proxy color sensors. Our work in these years informed us on the important parameters (sensor size/shape, camera distance/angle, and lighting conditions) for successful sensor localization. In YR3 we began the build of a robust ground-robot platform to integrate all intended components of the system.

In this YR4 reporting period, we have drastically improved upon the robot platform and have successfully demonstrated the integrated robotic imaging pipeline indoors while making significant progress towards its outdoor demonstration. This was achieved through the following: The robot platform was integrated with a SparkFun RTK-GPS unit on board (Fig 1) for GPS-IMU based waypoint following and navigation to the given GPS prior. It was also integrated with a Realsense T265 tracking camera for VIO-based robot localization in GPS-denied environments such as under crop canopy. The availability of both methods enable reliable robot localization and autonomous navigation. In the information gathering pipeline component of the system, we fuse GPS and IMU information using an Extended (and alternatively an Unscented) Kalman Filter for robot localization and navigation. Randomly exploring a random tree (RRT) is used to determine an optimal global plan for the robot, based on an assumed prior obstacle map or map of the row crops or orchard. A YOLOv7 model was successfully trained to localize the sensors in various lighting conditions (Fig 2). Upon detecting a leaf sensor, the robot completes a maneuver to position the leaf sensor in the field of view of the hyperspectral camera. A homography algorithm is used to map the location of the sensor in the RGB image to the SpectralZoom mirror's coordinate system for hyperspectral image acquisition. Finally, we conducted hyperspectral imaging indoors

and outdoors of various colorimetric sensors and identified the necessary requirements for successful measurement of the sensor's spectral response in daytime and nighttime lighting. From these measurements, we have determined that the resonance modulation must be greater than 40% for the signal-to-noise ratio to be sufficient for measurement by the hyperspectral camera. We have also identified two wavelength regimes in which we can design the sensors to operate: The shorter visible wavelengths (~550-650nm) in which leaf reflectance is low and the sensor resonance will appear as a peak. This wavelength regime is ideal for outdoor measurements using sunlight illumination since there are no interfering features in the solar radiation spectrum; The longer near-IR wavelengths (~750-850nm) in which leaf reflectance is highest and therefore, the sensor resonance will appear as a dip. This wavelength regime is ideal for indoor or nighttime measurements using artificial halogen light illumination, since there are absorptions/features in the solar radiation spectrum. We successfully demonstrated the daytime and nighttime measurement of two sensors on leaves, outdoors, with the SpectralZoom camera as seen in Fig 3.

Fig 1: Robot Hardware



1. Realsense T265 Tracking Camera
2. SpectralZoom Hyperspectral Camera
3. FLIR Chameleon3 USB3 RGB Camera
4. On-board Illumination
5. Jackery Portable Power Station
6. SparkFun RTK GPS module

Fig 2: YOLOv7 Sensor Localization Under Various Indoor/Outdoor Lighting Conditions

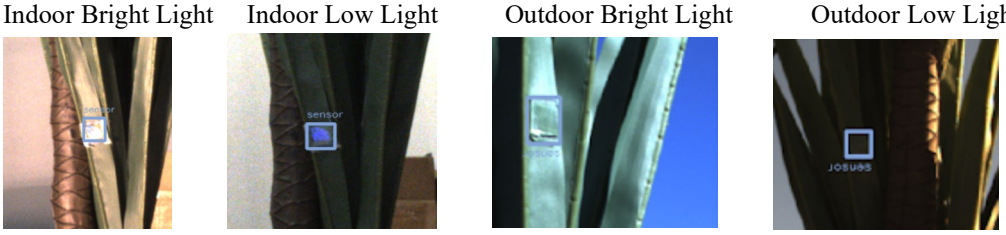
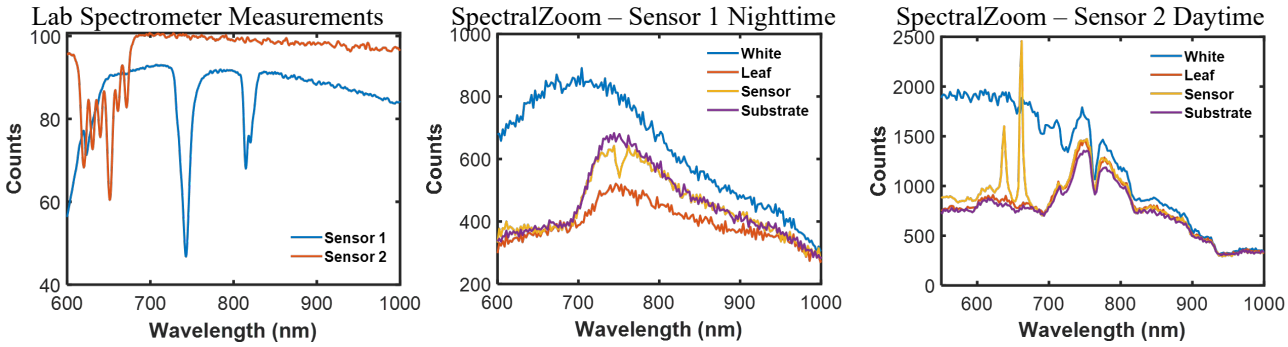


Fig 3: Sensor Spectral Response Measurements



TESTBED & JOINT-OPACTIVITY:

In March 2024, the team collaborated in-person at UPenn and successfully integrated the SpectralZoom camera from the University of Florida with the ground robot from UPenn. In June 2024, we conducted field testing of the SpectralZoom camera at the UC Merced testbed site. We conducted discrete testing of the SpectralZoom camera and sensor components of the system. We were able to successfully replicate the outdoor daytime results of Sensor 2 shown in Fig 3. We plan to conduct further outdoor field testing of the entire robotic imaging pipeline in Fall 2024.

Project Title: 2_OPTICAL ZOOM: Sensor and Detector

Thrust(s): Thrust 1 – Agricultural Sensor Systems / Thrust 3 – Agricultural Response System **ARL / TRL:** 3 / 5

Faculty Investigators: Sanjeev Koppal (Florida), Cherie Kagan, Vijay Kumar (Penn), Dave Cappelleri (Purdue)

Researcher(s): Kramadhati, Li, Hopkins, Lawrence, Murali, Mallavarapu (Penn), Arnold (Florida)

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PROJECT OVERVIEW

Optical metasurface-based leaf sensors being developed in 1_LEAFSENSE can directly measure plant health conditions and communicate this information via optical signals detectable by agricultural aerial/ground-based remote sensing imaging systems. The purpose of this project is to codesign (1) optical sensors; (2) physical mobile platform for information gathering, and (3) methods for optical detection and data analysis.

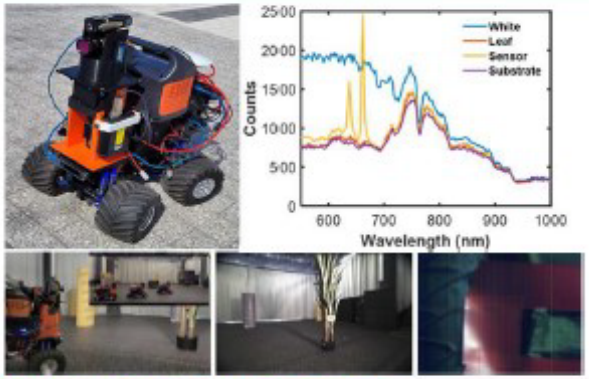
Key research goals include (1) integrating additional on-board sensors; (2) developing a pipeline that allows for autonomous acquisition of this information, based on a physical platform that was built in YR3, and (3) demonstrating the end-to-end pipeline indoors, towards outdoor deployment.

SUMMARY FIGURE

Top left: Ground robot platform equipped with RGB camera for colorimetric leaf sensor detection, hyperspectral camera for colorimetric leaf sensor spectra acquisition, and RTK GPS and tracking camera for autonomous robot localization and navigation.

Top right: Outdoor measurement of sensor's resonance with SpectralZoom camera.

Bottom: Indoor end-to-end pipeline of navigating towards GPS prior, detecting colorimetric leaf sensor, and acquisition of spectra.



RESEARCH APPROACH & BARRIERS

- For the ground robot platform to autonomously acquire information from the colorimetric leaf sensors, we focused on developing individual subsystems (colorimetric leaf sensors, navigation, colorimetric leaf sensor detection, hyperspectral imaging).
- In YR4, the team (Penn, UF) collaborated at Penn to physically equip the ground robot platform vehicle with the SpectralZoom hyperspectral camera.
- A pipeline that integrated these subsystems was developed and tested.
- To quantify design specifications for the colorimetric leaf sensor, experiments were conducted to acquire spectra using the SpectralZoom hyperspectral camera from colorimetric leaf sensors mounted on crops in the UC Merced testbed.

KEY ACCOMPLISHMENTS TO-DATE

- Completed integration of the SpectralZoom hyperspectral camera on-board and achieved homography between it and the RGB camera.
- Integration of the RTK GPS unit and tracking camera on-board which enables accurate autonomous robot localization and navigation based on GPS-IMU and VIO.
- Successful indoor demonstration of end-to-end imaging pipeline with significant progress (robot ruggedization and sensor optimization) towards outdoor demonstration.
- Iterative bench-testing of several colorimetric sensors to identify necessary sensor requirements for outdoor measurement.
- Successful measurement of sensor resonance outdoors with the hyperspectral camera both at Penn and at the UC Merced testbed site.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 3_SUBSURFACE SENSE: Passive, Sub-Surface Biodegradable Sensors and Components

Thrust(s): Thrust 1_Agricultural Sensor Systems/Thrust 2_Communication and Energy Systems

Lead Faculty Investigator: Troy Olsson (Penn)

Co-Investigator(s): Mark Allen, Cherie Kagan, Kevin Turner, Paulo Arratia (Penn), Small (Florida)

Researcher(s): Zaccarin Schell, Machold, Xu, Singh, Agarwal, Boyd, Lyu, Mallick (Penn), Pulvarthi, Sripati, Petersen (REU/Penn)

LOCATION ON 3-PLANE DIAGRAM: 2. Enabling Technology

TRL #: 4 **ARL #:** 2

OBJECTIVES & CENTER ALIGNMENT:

This project investigates sensing beneath the soil surface with high spatial density, minimal-to-zero materials left behind in the soil, and low sensor cost. Our ultimate goal is to develop a biodegradable, wireless sensor platform capable of measuring soil moisture, pH, nutrients, and/or compaction up to 1 m below the soil surface. Our systems will enable wireless sensor interrogation from either a drone or agricultural equipment at a range >10 m. Furthermore, we will develop materials, manufacturing methods, and architectures that enable sensor cost < $0.10.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

Project Overview - To achieve the project goals, the many different system components outlined below and shown in Figure 1 must come together (see Figure 1). Two journal papers and 1 conference paper appeared in press and 5 presentations were given in Y4.

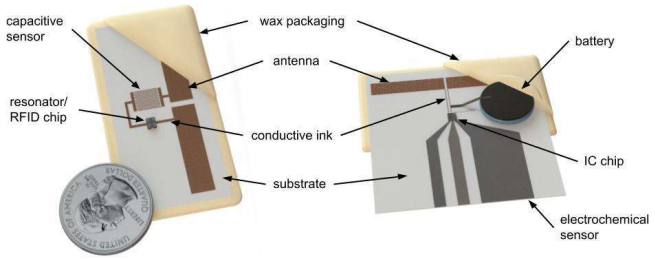


*Figure SEQ Figure * ARABIC 1. left) Passive subsurface sense system rendering and right) active subsurface sense system rendering*

CNF-Cardstock Composite Substrate Fabrication - Previous development of a fully biodegradable cellulose-based substrate led to capacitive moisture sensors printed on Nanocellulose coated cardstock. In year 4, the manufacturing of cellulose nanofibril coated cardstock was optimized to get repeatable surface properties on larger areas.

Wireless Soil Moisture Sensor Packaging and Testing - In Year 3, a wireless completely biodegradable soil moisture sensor node was designed and fabricated. Through loose inductive coupling, the interrogator coil can determine the resonant frequency of the sensor node. As soil moisture increases, the capacitance of the sensor increases while its inductance remains constant, decreasing the resonant frequency of the sensor node. This wireless moisture sensor was screen printed on a fully biodegradable substrate and packaged in beeswax to improve sensor lifetime. Benchtop testing of sensor response to changing soil moisture was conducted to design interrogation procedures. Preliminary testing was used to understand the lifetime of unpackaged and wax packaged sensors.

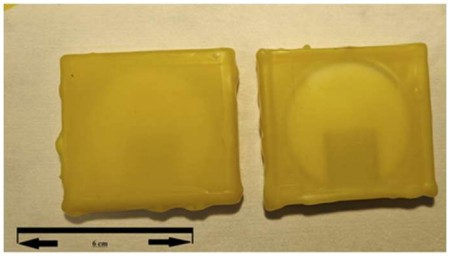


*Figure SEQ Figure * ARABIC 2. Wireless soil moisture sensor packaged in beeswax.*

Wireless Interrogation Leveraging High-Q Acoustic Resonator - The long range wireless sensor interrogation concept was explored using a surface acoustic wave (SAW) resonator design in the 902-928 MHz Instrumental Scientific Medical (ISM) band. The SAW was connected to a dipole antenna and wirelessly interrogated at a range of 3 m where the reradiated energy from the passive system could clearly identify the SAW resonant frequency which in the future will be pulled in frequency by capacitive sensors (such as soil moisture and nitrate).

Nitrate Sensor - The nitrate sensor consists of an Ag nanoparticle capacitor with a nitrate ion-selective membrane (ISM) coated on top fabricated on a Kapton substrate. Before testing the sensor performance in soil, its performance was tested in aqueous nitrate solutions with nitrate concentration ranges typically observed in soil (1-70 ppm) and capacitance change was measured (Figure 3). A droplet (10 µL) was applied sequentially with increasing nitrate concentration and capacitance was recorded. The capacitance increases linearly with the increase in the nitrate concentration (right). The sequence was repeated four times to show the reproducibility of the sensor.

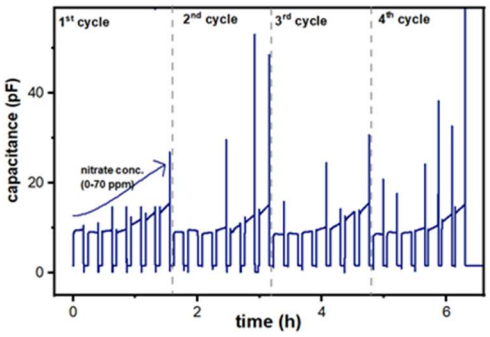


*Figure SEQ Figure * ARABIC 3. Capacitance measured from nitrate sensor for four cycles of sequential increase in nitrate*

Phosphate Sensor - Environmental water samples were collected from agricultural areas, including tile drains in Indiana and irrigation canals and ditches in South Florida. These samples were measured with our phosphate sensor and a traditional lab technique, flow injection analysis (FIA). Results suggest that pH adjustment is necessary to avoid silicate interference and SWV is needed to achieve adequate limit of detection. Previous works in the literature have applied these same techniques for phosphate detection in seawater (Barus et al., Talanta, 2016).

Chemically-Driven Sintering of Colloidal Cu Nanocrystals for Screen-printed RF Sensors – We exploited our prior year's research on biodegradable Cu NC inks and demonstrated RF devices operating in the targeted 902-928 MHz ISM band. The Cu NC-based sensors have capacitances comparable to those of devices fabricated using thermal evaporation of Cu and Q-factors similar to sensors fabricated with commercial Ag NC inks. We also prepared Cu NC inks with increased viscosities suitable for screen printing, by incorporating α-terpineol in hexane.

TESTBED & JOINT-OP ACTIVITY:

Screen-printed wireless soil sensors were brought to Purdue University's Agronomy Center for Research and Education (ACRE). Eight sensors were buried at varying depths up to 5 cm. Data collected from the sensors was then compared to volumetric soil moisture data available at the Purdue Mesonet Data Hub weather station. Figure 4 shows the behavior of two sensors buried at different depths overlaid with the weather station soil moisture data. According to weather station data, it rained 0.09 inches the first night the sensors were buried and otherwise the weather was dry. From the figure we can conclude that the shallower sensor responded to the small amount of rainfall, while the sensor buried deeper did not.

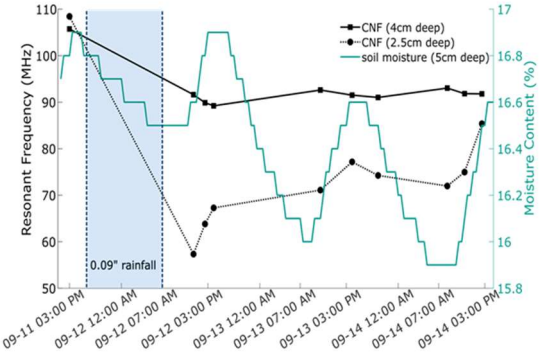


*Figure SEQ Figure * ARABIC 4. sensor resonant frequency over a 72h period and reference soil*

Project Title: 3_SUBSURFACE SENSE: Passive, Sub-Surface Biodegradable Sensors and Components

Thrust(s): Thrust 1_Agricultural Sensor Systems / Thrust 2_Communication and Response Systems **ARL / TRL:** 2 / 4

Faculty Investigators: Olsson, Allen, Kagan, Turner, Arratia (Penn), Small (Florida)

Researcher(s): Zaccarin, Schell, Machold , Xu, Boyd, Pradeep, Iyer, Singh, Agarwal, Lyu, Mallick, Chang, Zhang (Penn), Pulvarthi, Sripati, Petersen (REU)

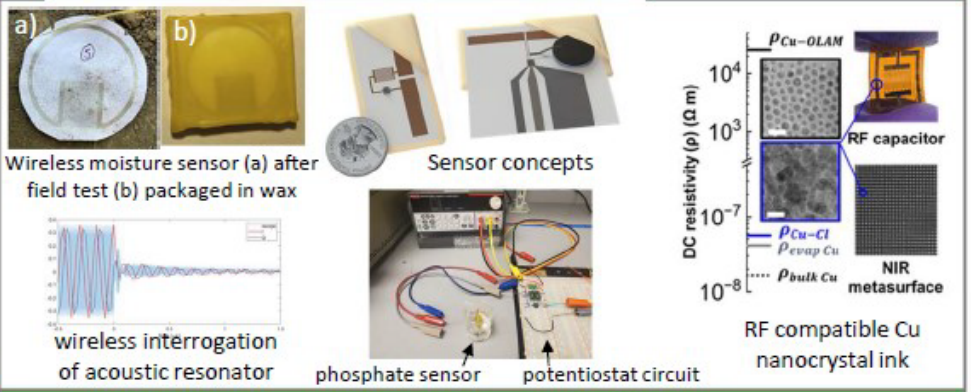
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The Internet of Things for Precision Agriculture
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PROJECT OVERVIEW

This project investigates sensing beneath the soil surface with high spatial density, minimal-to-zero materials left behind in the soil, and low sensor cost. Our ultimate goal is to develop a biodegradable, wireless sensor platform capable of measuring soil moisture, pH, and/or nutrients up to 1 m below the soil surface. Our systems will enable wireless sensor interrogation from agricultural equipment at a range >10 m. Furthermore, we will develop materials, manufacturing methods, and architectures that enable sensor cost < $0.10.

Y5 Milestones include integrating an acoustic resonator with a nanocellulose moisture sensor and interrogating it wirelessly using a software defined radio in a Joint-Op field setting, printing the Cu nanoparticle inks on the CNF substrate, and selecting circuit architectures appropriate for active phosphate and nitrate sensors.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Traditional wireless sensor approaches use high quality/cost components. We investigate two architectures: passive wireless to minimize components and active wireless that enables electrochemical sensing and data logging. Both approaches explore biodegradable conductive inks/metals, dielectrics (e.g. cellulose), and polymer sensors amenable to low-cost manufacturing which we have demonstrated separately. Now, we're working on integrating these components. Furthermore, we must ensure the selectivity of our sensors without compromising on other design requirements. Passive wireless interrogation will be further tested as part of a Joint Op in the 2025 growing season. Current barriers include short in-soil lifetime of available biodegradable materials, manufacturing limitations on sensor size, and poor interfacing of various electrical components.

KEY ACCOMPLISHMENTS TO-DATE

- Wireless soil moisture sensors screen printed on CNF coated cardstock using Ag nanoparticle inks and tested in the field at ACRE (Purdue)
- Cu nanocrystal inks used to fabricate capacitors on Kapton substrates and glass; viscosity of Cu inks tailored for screen printing
- Phosphate sensor tested in solutions extracted from soil and additional improvements necessary for use in this environment were identified
- Phosphate sensor integrated with potentiostat circuit implemented on breadboard
- Extended functional lifetime of sensors in soil using wax-based packages
- Demonstrated wireless interrogation using a high-Q acoustic resonator towards long range passive wireless sensing
- Measured capacitive nitrate sensor over nitrate levels found in soils

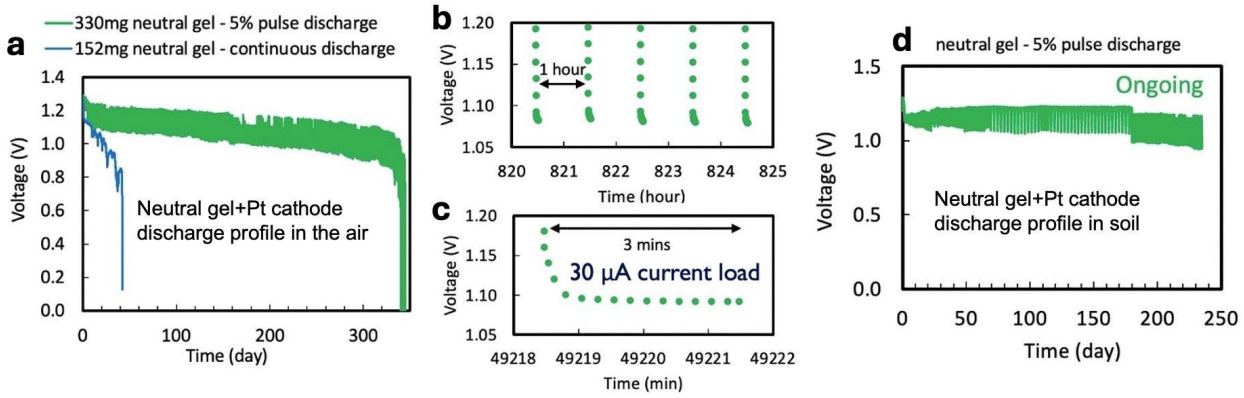
YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 4_AIR-BATTERIES: Biodegradable Air Batteries for Distributed Sensing
Thrust(s): Thrust 2 – Communication and Energy Systems / Thrust 1 – Agricultural Sensor Systems
Lead Faculty Investigator: Mark Allen (Penn)
Co-Investigator(s): Troy Olsson (Penn), Tony Vyn (Purdue)
Researcher(s): Zhang, Beeman (PhD/Penn), Lyu (MS/Penn)

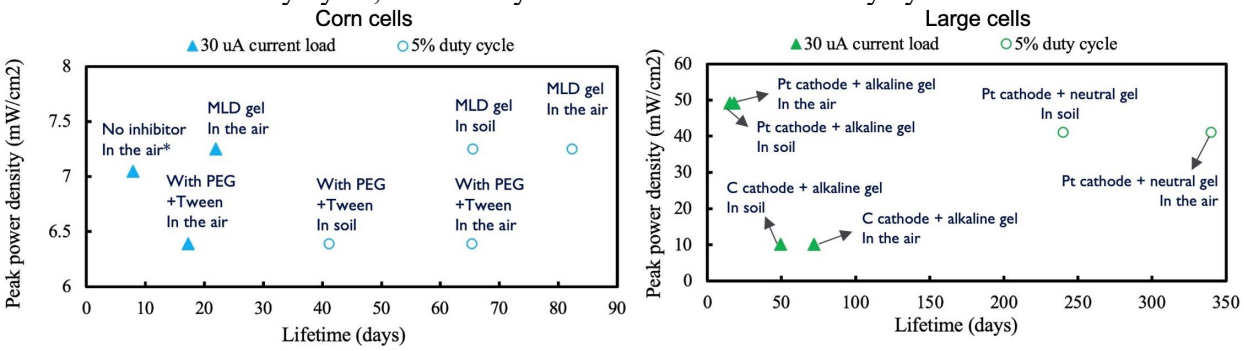
LOCATION ON 3-PLANE DIAGRAM: 2. Enabling technology
TRL #: 6 **ARL #:** 3

OBJECTIVES & CENTER ALIGNMENT:
High-resolution soil data is desired for agricultural and environmental sciences, which can be achieved by using subsurface wireless sensing platforms. For sensing platforms that contain an active electrochemical sensor, or need data transmission over a long distance, a battery is needed to power the system. Biodegradable batteries can be disposed of after use without recollection

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
The neutral gel is used to extend the battery lifetime. It has a near-neutral pH and can effectively prevent side reactions that occur in alkaline gels and reduce Zn self-corrosion rate. Neutral gels (PVA, NH_4Cl, and DI water) were fabricated and assembled into batteries with Pt-loaded cathodes. Batteries discharged under 5% duty cycle for 340 days in the air, and over 235 days in soil.



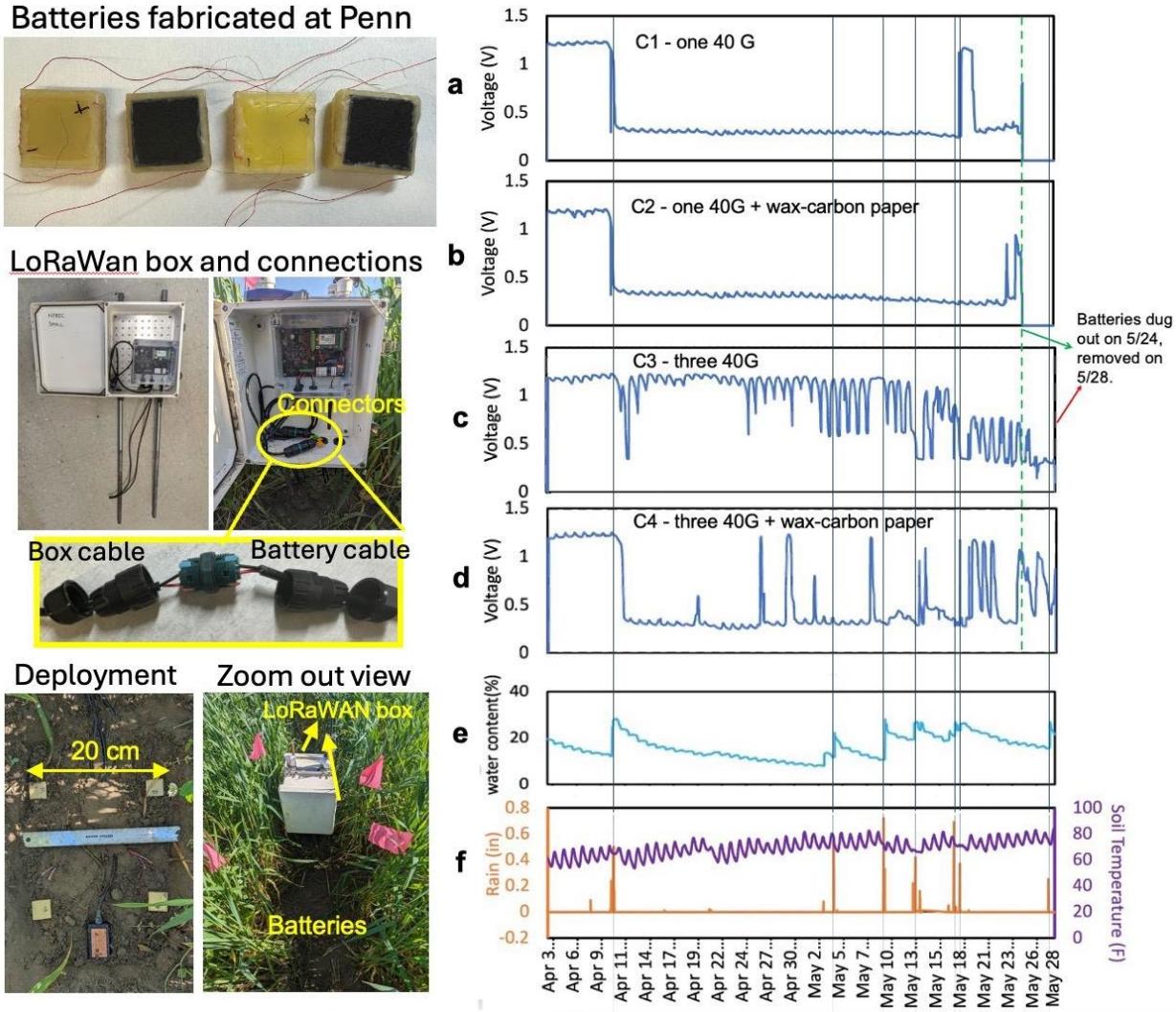
Corn cells' lifetime was further extended using the biodegradable inhibitor Maltodextrin (MLD), which is introduced in the gel. The corn cell discharge for 21 days in the air under 30 uA, 65 days in soil under a 5% duty cycle, and 82 days in the air under a 5% duty cycle.



The large-cells (2x2x0.7 cm^3) peak power density range from 10 to 50 mW/cm^2, and lifetime range from 15 days to 340 days, with different battery constructions and operational environments.

TESTBED & JOINT-OP ACTIVITY:

Field tests were conducted to characterize batteries' performances in a natural environment. Batteries are integrated with LoRaWAN in collaboration with Andrew, Fabio, Edinson (Purdue), and Elizabeth (Penn) to collect their working voltage in the field, and remotely monitor their performances. Four batteries were deployed and tested in the UF testbed 2024 Spring, with an enhanced wax package design and improved electrical connections between different parts. Battery working voltage under 47 kΩ resistor load was collected and analyzed together with the local soil temperature, soil moisture content, and local precipitation. All batteries discharge at 1.2 V for a week, till heavy precipitation. After which, C3 with three 40 G air paths voltage recovered. Other batteries had lower working voltage afterward, potentially due to constrained access to the air. The daily fluctuation of battery working voltage is found to follow the temperature change over a day.



Project Title: 4_AIR BATTERIES: Biodegradable Air Batteries for Distributed Sensing

Thrust(s): Thrust 2 – Communication and Energy Systems / Thrust 1 – Agricultural Sensor Systems **ARL / TRL:** 3 / 6-7

Faculty Investigators: Mark Allen (Penn), Troy Olsson (Penn), Tony Vyn (Purdue)

Researcher(s): Zhang, Beeman, Lyu (Penn)

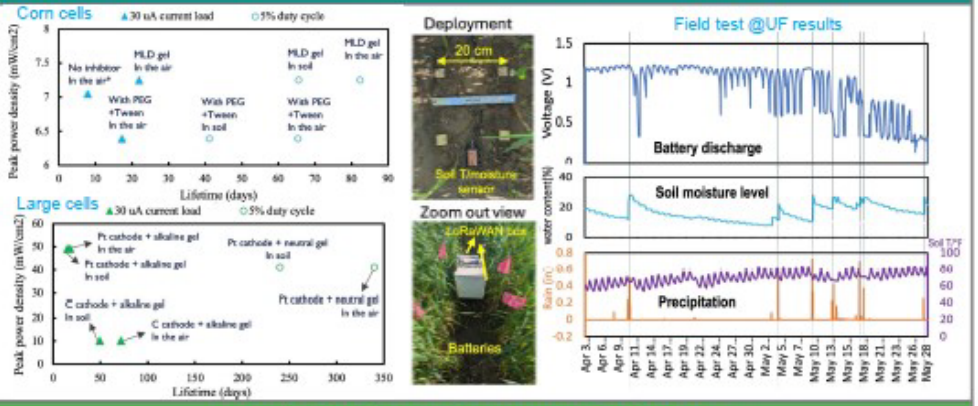
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PROJECT OVERVIEW

Project Goals: Some sensing modalities, such as chemical sensors employing electrochemical redox reactions, sensors that require data logging, or sensors that require data communication capability over relatively long distances, may require onboard power. The power source should both be sufficient to meet the application need, as well as degrade in a biocompatible fashion after use or exhaustion. This project proposes using Zn-air batteries in biodegradable polymer packages with hydrogel electrolyte as energy sources for chaff sensors. We are fabricating these devices, adapting them to match lifetime based on sensor requirements, and understanding their degradation behavior.

Location on 3-Plane Diagram: Enabling Technologies

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Approaches in Year 3: Investigate the neutral gel to extend the battery lifetime. It has a near-neutral pH and can effectively prevent side reactions that occur in alkaline gels, and reduce Zn self-corrosion rate. Neutral gels (PVA, NH4Cl, and DI water) were fabricated and assembled into batteries with Pt-loaded cathodes. Corn cells' lifetime was further extended using the biodegradable inhibitor Maltodextrin (MLD), which is introduced in the gel. Its polar functional groups can potentially attach to the Zn anode, forming a protective layer to avoid self-corrosion.

IoT4Ag Testbeds and/or JointOps
Batteries are integrated with LoRaWAN in collaboration with Andrew, Fabio, Edinson (Purdue), and Elizabeth (Penn) to collect their working voltage in the field, monitoring their performances remotely. The integrated system was deployed at the UF testbed

KEY ACCOMPLISHMENTS TO-DATE

- Achieved 21 days of continuous discharge of corn cells in the air
- Achieved 82 days of discharge of corn cells with MLD gel in the air, and 65 days in soil, both under 1/20 discharge duty cycle
- Achieved 340 days discharge of cm-scale air batteries with neutral gel electrolyte in the air, over 235 days in soil, both under 1/20 duty cycle
- Integrated air batteries with LoRaWAN communication systems and deployed them at the UF testbed with improved electrical connections. Over 50 days discharge of the air battery (cm-scale) was achieved
- Opened microchannel air paths on the wax package with the designed amount of oxygen flux for battery operation (to minimize exposure to the natural environment)

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 7 EDGE COMP-COMM: Edge Computing and Communication for Agricultural Sensors
Thrust(s): Thrust 2 – Communication and Energy Systems
Lead Faculty Investigator: James Krogmeier (Purdue)
Co-Investigator(s): David Love, Dennis Buckmaster (Purdue)
Researcher(s): Castiblanco Rubio, Arun Natraj Arun, Lee, Malayter, Balmos (PhD/Purdue)

LOCATION ON 3-PLANE DIAGRAM: 1. Fundamental knowledge / 2. Enabling technology
TRL #: 1 (ISAC4Ag), 3 (AG2UG RFID), 6 (OATSMobile)
ARL #: 1 (ISAC4Ag), 2 (AG2UG RFID), 2 (OATSMobile)

OBJECTIVES & CENTER ALIGNMENT:
This project aims to leverage wireless communications and machine-based edge computing. Machines travel throughout the farm and provide opportunities to connect large areas. Though mobile, these machines usually travel slowly over time. Additionally, machines have sufficient power and space to support moderate-to-high power and large-sized electronics that can pre-process data and reduce the burden of field-to-cloud data transport over rural backhauls. This work builds on the existing ISOBlue and Avena projects to extend its application beyond the CAN bus to general purpose edge-computing; supporting a host of radios and backhauls. Finally, we consider the proper role of Radio Frequency Identification (RFID) as the technology for underground communications in agriculture, using ISOBlue as the computing solution, Avena as the software stack for integrating data flows from disparate sensor technologies. This project aligns well with IoT4Ag because there is an urgent necessity for higher-rate sensor communication, particularly technologies that can operate in the harsh conditions of the agricultural use case.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

- **Approach in Year 1:** Design, simulate, and characterize performance for inductive wireless powered communication for agricultural sensor devices. Develop theory that establishes a notion of capacity subject to an adversary's capabilities, where adversaries were able to attempt to corrupt sensor signals. Develop coding schemes that achieve target capacity in specific cases, allowing communications without sophisticated high-layer encryption.
- **Approach in Year 2:** Develop and integrate software to interact with radio hardware using the Avena software stack. By exploring technologies such as LoRa and Wi-Fi, building and deploying the Purdue OATS Data stations (PODs) in the testbed at the Purdue ACRE farm allow the integration of ISOBlue edge-computers in the design and simulation of a Delay Tolerant Network (DTN).
- **Approach in Year 3:** Design and develop a platform for underground communications with agricultural machinery based on the ISOBlue edge-computer and the Avena software stack. Using RFID as the technology for sensor to machine communications allows the integration of sensor technologies developed in other projects within the ERC. In addition,

we initiated our investigation on a novel approach called integrated sensing and communication (ISAC) for agriculture. We developed a signal processing algorithm for ISAC systems to bolster agricultural imaging using communication infrastructure.

- **Approach in Year 4:** Conduct an evaluation and survey of existing commercial RFID communications solutions using the OATSMobile platform developed in Year 3. This technology evaluation allows identification of implementation challenges of backscatter communications between edge computers and underground wireless sensor networks. Factors such as channel multiple access, backscatter signal propagation through soil, transponder fabrication tolerance, transponder antenna design, transponder form factor, transponder antenna orientation, and interrogation device operation modes have been identified as limiting factors for wireless soil sensing applications.

Key activities and Milestones:

- Developed theory that established a notion of capacity subject to an adversary's capabilities, where adversaries were able to attempt to corrupt sensor signals.
- Developed coding schemes that achieved target capacity in specific cases, allowing communications without sophisticated high-layer encryption.
- Developed a framework for inductive WPCNs that captured network properties using small numbers of measurable parameters
- Developed a new approach to maximize the efficiency of inductive WPT using multiple coil charging systems.
- Designed and conducted a series of controlled experiments to test and analyze the performance of RFID transponders in aboveground to underground communications scenarios. Factors such as channel multiple access, transponder depth, transponder size, transponder antenna orientation, and transponder fabrication tolerance were considered to affect the received signal strength in these trials.
- Designed a field testbed experiment to study the performance of an RFID communications channel under different soil conditions, considering factors such as soil moisture, plant population, scanning height, and scanning speed.
- Collected a data set based on received signal strength from each antenna, sensor read rate, machine position, machine speed, and soil moisture in the field.

TESTBED & JOINT-OP ACTIVITY:

- Field testing of the underground communications platform based on RFID is being conducted in Field 22C at the Purdue ACRE Testbed, collecting data in soil with a single drainage class, ensuring consistency across tests between different sensor classes.

Project Title: 7_EDGE COMP-COMM: Edge Computing and Communication for Agricultural Sensors

Thrust(s): Thrust 2 **ARL / TRL:** 1 (ISAC4Ag), 2 (AG2UG RFID), 2 (OATSMobile) / 1 (ISAC4Ag), 3 (AG2UG RFID), 6 (OATSMobile)

Faculty Investigators: James Krogmeier, David Love, Dennis Buckmaster (Purdue)

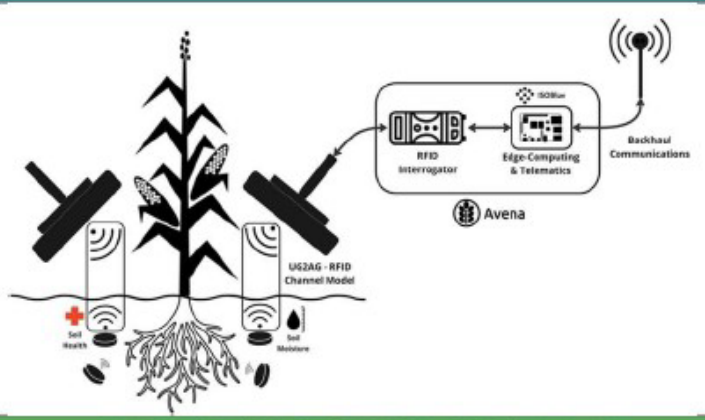
Researcher(s): Castiblanco Rubio, Natraj Arun, Lee, Malayter, Balmos

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PROJECT OVERVIEW

This project aims to leverage wireless communications and machine-based edge computing. Machines travel throughout the farm and provide opportunities to connect large areas. Though mobile, these machines usually travel slowly over time. Additionally, machines have sufficient power and space to support moderate-to-high power and large-sized electronics that can pre-process data and reduce the burden of field-to-cloud data transport over rural backhauls. This work builds on the existing ISOBlue and Avena projects to extend its application beyond the CAN bus to general purpose edge-computing; supporting a host of radios and backhauls. Finally, we consider the proper role of Radio Frequency Identification (RFID) as the technology for underground communications in agriculture, using ISOBlue as the computing solution, Avena as the software stack for integrating data flows from disparate sensor technologies. This project aligns well with IoT4Ag because there is an urgent necessity for higher-rate sensor communication, particularly technologies that can operate in the harsh conditions of the agricultural use case.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Approach in Year 1: Develop theoretical frameworks for secure communications via waveform security and models for efficient wireless power transfer in WPCNs.

Approach in Year 2: Develop a software framework to integrate communications equipment with edge-computing nodes in agricultural vehicles.

Approach in Year 3: Design and develop a platform for AG2UG RFID communications based on the ISOBlue edge-computer, the Avena software framework, and the OATSMobile platform.

Approach in Year 4: Evaluate and survey existing commercial RFID communications solutions using the OATSMobile platform to identify implementation challenges of backscatter communications between edge computers and underground wireless sensor networks.

Testbed & Joint-Op Activity: Field testing of the underground communications platform based on RFID is being conducted in Field 22C at the Purdue ACRE Testbed, collecting data in soil with a single drainage class, ensuring consistency across tests between different sensor classes.

Barriers: Commercial RFID communications systems feature proprietary protocol implementations that often make application-specific integrations and adaptations difficult.

KEY ACCOMPLISHMENTS TO-DATE

Physical Layer Communications Channel Security

Developed theory that established a notion of capacity subject to an adversary's capabilities, where adversaries were able to attempt to corrupt sensor signals. Coding schemes achieved target capacity in specific cases, allowing communications without sophisticated high-layer encryption.

Inductive Wireless Power Communications

Developed a framework for inductive WPCNs that captured network properties using small numbers of measurable parameters. This approach maximizes the efficiency of inductive WPT using multiple coil charging systems.

RFID Communications Systems Characterization

Designed a series of controlled experiments to test the performance of RFID transponders in aboveground to underground communications scenarios. Factors such as channel multiple access, transponder depth, transponder size, transponder antenna orientation, and transponder fabrication tolerance were considered in these trials.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 8_AGBOT: Crop-Sampling Unmanned Ground Vehicle (UGV)
Thrust(s): Thrust 1_Agricultural Sensors Systems / Thrust 2_Communication and Energy Systems
Lead Faculty Investigator: David J. Cappelleri (Purdue)
Co-Investigator(s): Melba Crawford, Dan Quinn, Jim Krogmeier, Tony Vyn (Purdue); Vijay Kumar (Penn)
Researcher(s): Kim, Deb, Aviles Toledo (PhD/Purdue), Liu (PhD/Penn), Hanson, Oliva (MS/Purdue), MacDonald (Undergrad/Purdue), Chen, Luna (Undergrad/REU)



LOCATION ON 3-PLANE DIAGRAM: (2) Enabling technology; (3) Systems
TRL: 6 **ARL:** 3

OBJECTIVES & CENTER ALIGNMENT:
The objective of this project is to design and test an autonomous unmanned ground vehicle (UGV)/mobile robot capable of monitoring and sampling corn leaves at optimal spatial locations at various time-points during the growing season. The whole-leaf samples obtained at different height positions (depending on the stage) will be analyzed for crop stress, such as water, nitrogen, and potassium deficiencies. The UGV will be equipped with a sensor suite for obtaining additional morphological data such as stem diameter and ear height. Drone imagery will be scheduled to coincide with some of the UGV sampling to add above-canopy imagery for stress detections. Whole-plant biomass and nutrient concentration samples will be taken to relate to the leaf-specific data from composite leaf samples for corn plants ranging from 25 to 300 cm in height.

This project is aligned with the strategic goal of IoT4Ag to create integrated systems that provide early detection of plant stress and environmental conditions in the field. Currently, it aligned with Joint Op 1: Integrated systems to optimize N application in row crops. In future, it will be extended to investigate other crop stresses, such as water and potassium deficiencies, for optimizing mitigation strategies, and crop disease detection. Additionally, this UGV platform can eventually be used for deploying the sensors of Project 1_LEAFSENSE to individual crop leaves; burying and interrogating the subsurface sensors of Project 3_SUBSURFACE SENSE; and used to mounting the sensor/detector developed in Project 1_OPTICAL ZOOM.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
P-Ag SLAM (Simultaneous Localization and Mapping): We have continued to develop a Simultaneous Localization and Mapping (SLAM) framework specifically designed for in-row and under-canopy localization and agricultural monitoring in cornfields, denoted as Purdue AgSLAM (P-AgSLAM). The proposed SLAM framework aims to reduce odometry drift and accurately estimate robot trajectories in cluttered, repetitive-feature-rich, and GNSS-denied agricultural environments. The P-AgSLAM framework is composed of two main modules: The proposed P-AgSLAM framework consists of two primary modules: LiDAR-based feature extractor and a robot state estimator using a factor graph with optional GPS measurements. The two modules collaboratively minimize drift and publish accurate robot poses and maps. Our systematic

framework is robust at both extracting more reliable and representative features from cornfields and accurately estimating robot pose as compared to baseline methods which primarily focus on structured geometric features. Both feature extraction and GPS integration are critical components that enhance the accuracy of our pose estimation system from individual perspectives. Feature extraction accurately estimates positions and orientations at a local level, essential for precise in-row navigation and under canopy monitoring. Conversely, GPS integration extends this precision to a global scale, ensuring consistent and reliable navigation over long distances. However, the feature extractors and state estimators used by baseline methods do not specifically identify or distinguish repetitive corn characteristics, making it challenging to determine whether the robot traverses between corn rows or stays in the same position.

Autonomous Navigation System for Large-Scale Cornfields: Single-row autonomous navigation for the P-AgBot has been demonstrated in the prior reporting period. For operation in large-scale cornfields with many rows, additional modules are required. During this reporting period, we have been developing an autonomous navigation framework consisting of in-row navigation, path recovery, in-row/out-row classification, out-row navigation, and crop counting. It utilizes the range view images from a single 3D LiDAR for sensing along with model predictive control. The algorithm has been assessed in simulation and is currently being evaluated and refined in the ACRE testbed at various corn growth stages.

Transformer-Based Approach for Leaf Pose Estimation for Physical Sampling: Previously, we utilized a Mask R-CNN model for detecting bounding boxes of the corn leaves and a YOLOv5 neural network for leaf collar detection. This allowed for the 2D estimation of the leaf angle. This was challenging to realize in the presence of occluded leaves. The image data and depth accuracy can also be affected by the outdoor lighting conditions. Therefore, we have moved to using Mask2Former, a transformer-based approach. It consists of a self-attention mechanism and panoptic segmentation. Transformers can model global dependencies in the data, allowing them to better understand complex scenes with overlapping objects. Masks are predicted directly from a set of learnable queries with an end-to-end approach, more efficiently than before.

Corn Ear Height Measurements: We have developed an algorithm to measure the distance from the ground to the point where corn ear attaches to the stalk. The algorithm uses a trained YOLOv8 object detection network to identify the corn earns, and keypoints from the aligned RGB and depth images. It has been tested on artificial plants with 2 corn ears per plant: Average error for the lower and higher ears are 1.1cm and 1.6 cm, respectively.

TESTBED & JOINT-OP ACTIVITY:

Fieldwork for this project has been and is continuing to be performed at the ACRE testbed facility at Purdue University as well as the Purdue greenhouses. P-AgSLAM has been thoroughly tested against baseline methods and generated 3D maps at ACRE. Multi-row autonomous navigation tests have been and are being performed; training, baseline, ground truth, and sensor data obtained at various corn growth stages; and physical sampling experiments will be performed once corn plants are matured. This project fits with Joint Op 1: Nitrogen application in row crops.

Project Title: 8_AgBot: Crop Sampling Unmanned Ground Vehicle

Thrust(s): Thrust 1 / Thrust 2 **ARL / TRL:** 3 / 6

Faculty Investigators: D. Cappelleri, M. Crawford, D. Quinn, J. Krogmeier, T. Vyn (Purdue); V. Kumar (Penn)

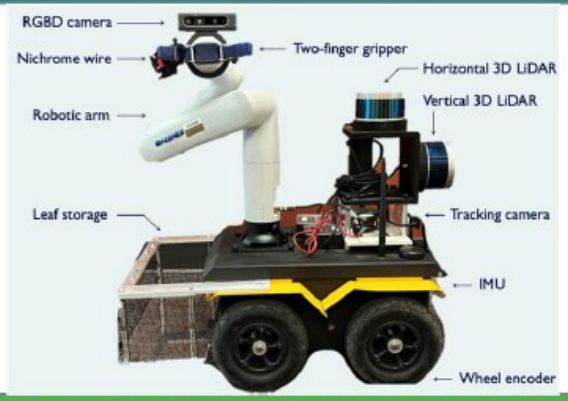
Researcher(s): Kim, Deb, Aviles Toledo, Hanson, Oliva, MacDonald (Purdue), Liu (Penn), Chen, Luna (REU)

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PROJECT OVERVIEW

Project Goals: The objective of this project is to design and test an autonomous UGV capable of monitoring and sampling crops at optimal spatial locations at various time-points during the growing season. The whole-leaf samples obtained at different height positions will be analyzed for crop stress. The UGV will be equipped with a sensor suite for obtaining additional morphological data such as crop diameter and ear height. Drone imagery will be scheduled to coincide with some of the UGV sampling to add above-canopy imagery for stress detections.
This project is aligned with the strategic goal to create integrated systems, that provide early detection of plant stress and environmental conditions in the field.
Testbeds and Joint Ops: Currently, it aligned with Joint Op 1: Integrated systems to optimize N application in row crops. In future, it will be extended to investigate other crop stresses, such as water and potassium deficiencies, for optimizing mitigation strategies.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Approach in Year 4:

- Field-test P-AgSLAM algorithm for simultaneous localization and mapping at ACRE and evaluate
- Develop an autonomous navigation algorithm for the P-AgBot tailored to unique environment of corn field
- Utilize new deep learning-based model in conjunction with RGB-D camera to determine 6 degree-of-freedom leaf pose information for improved physical sampling

Barriers: Difficult to obtain quality training data for machine learning algorithms for leaf detection, needed for close—loop sampling; traditional approaches for autonomous navigation will not work for in-row and under canopy driving.

KEY ACCOMPLISHMENTS TO-DATE

Accomplishments:

- Designed and prototyped and UGV platform capable of in-row and under-canopy navigation and physical sampling in corn fields (Y2); updated sensor suite (Y3).
- Developed P-AgSLAM: a LiDAR-based algorithm for simultaneous localization and mapping in corn fields (Y3); Validated in simulation and in testbed (Y4)
- Deep Learning-based Leaf Detection for Robotic Physical Sampling: Mask R-CNN and YOLOv5 approach (Y3); Transformer-based approach (Y4)
- Corn stalk height (Y2), radius (Y2), and ear height estimation algorithms (Y4)
- Developed P-AgNAV: a LiDAR-based navigation algorithm utilizing range-view images and model predictive control; validated in simulation (Y4).

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 9_SEMANTIC MAPPING: Semantic Mapping of Orchards for Yield Estimation
Thrust(s): Thrust 1_Agricultural Sensor Systems / Thrust 3_Agricultural Response Systems
Lead Faculty Investigator: Vijay Kumar (Penn)
Co-Investigator(s): Reza Ehsani (Merced), Pratik Chaudhari (Penn), Dave Cappelleri (Purdue)
Researcher(s): Liu, Cladera, Li, Das, Ong, Shao (PhD/Penn), Prabhu, Cheng, Lei (MS/Penn), Zhou (Staff/Penn), Mortazavi (PhD/Merced), Cruz, Ruiz (Undergrad/Merced), Chopra (REU)

LOCATION ON 3-PLANE DIAGRAM

This project is split roughly equally between Enabling Technologies (robotics, sensors, interpretable analytics) and Fundamental Knowledge (sensor fusion, machine learning)
TRL #: 7 **ARL #:** 6 – We have developed a robust robotic system for metric-semantic mapping and tree diameter estimation and tested our system in real-world settings such as orchards and forests. We are collaborating with UC Merced (an IoT4Ag university) and Virginia Tech (a non-IoT4Ag university), and they have adopted our system for their specific use cases.

OBJECTIVES & CENTER ALIGNMENT

We seek to develop autonomous and collaborative robotic systems to survey large-scale agricultural environments, gathering actionable information, and monitoring changes over time. This aligns well with IoT4Ag's goal of transforming agricultural practices and sustainably increasing the production of high-quality crops. A system that can estimate crop yields and enable farmers to detect signs of plant stress is key to improving resource utilization; these techniques are building blocks of IoT4Ag's grand vision of increasing food production. The focus on autonomous vision-based flight under canopy in densely planted fields aligns with the program's emphasis on innovative and integrated systems that are also cost-effective, a central tenet of the IoT4Ag mission.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD

Sparse, Lightweight, Decentralized Metric-Semantic SLAM for Multi-Robot Navigation. We developed a real-time decentralized metric-semantic SLAM approach that uses a sparse and lightweight object-based representation to enable a heterogeneous robot team to autonomously explore 3D environments without relying on GPS. It maintains a hierarchical representation of the environment, from high-level sparse semantic maps to low-level geometric maps. We use this to collaboratively build maps of trees, e.g., maps that include both fruits and tree trunks for orchard yield estimation purposes. We are also collaborating with the University of Maine and Virginia Tech to deploy this system for forestry management and extract actionable information such as the position, orientation, and stem taper profile of trees.

TreeScope. We created TreeScope, the first semantically segmented LiDAR dataset collected with robotic systems in agricultural environments. TreeScope provides LiDAR data and ground-truth data for semantic segmentation and diameter estimation from agricultural environments to address the counting and mapping of trees in orchards and forests. Raw data is available from UAV flights and our custom sensor platform, including sensor data from LiDAR, IMU, GPS, RGBD and thermal cameras (Fig. 1). We provide ground truth in the form of manually annotated semantic labels for the tree stems and field measurements of tree diameters.



Fig. 1. TreeScope data collection platforms.

Monocular event-based visual-inertial odometry (VIO). Event-based cameras measure intensity changes at individual pixels. We developed an "optimal" procedure to convert events into an equivalent multi-channel "video" (at any framerate). This is a fundamental advance towards building event-based visual odometry. Further, monocular VIO often does not recover scale correctly which makes it difficult to use in practice. It cannot be updated in run-time to address changes from the training environment. We developed an unsupervised approach for RGB/event VIO. Results so far suggest that we can recover orientation quite accurately.

Photorealistic maps of trees and foliage. We conducted a field trip to Virginia Tech to collect data from LiDAR and 360 cameras, and cross-check this with measurements of pine trees obtained from our collaborators. We have developed several techniques to process these different sensors and build accurate photometric and geometric maps (using NeRFs and Gaussian splatting-based methods) from this data. The eventual goal is to build a "digital twin of a farm". We have recently included an event camera into our sensor stack, and we are currently evaluating how this sensor could help NeRF reconstructions in challenging lighting conditions.

4D Metric-Semantic Mapping in Orchards. We developed an approach to combine geometric and contextual information over time to accurately depict the status of orchard vegetation. By fusing data from multiple sensors (LiDAR, RGB cameras, GPS, and IMU) can monitor tree and fruit growth, estimate yields, and identify spatial patterns and anomalies. This framework is capable of accurately extracting fruit sizes, colors, and tree trunk diameters. We built algorithms for tracking fruits within a single session and for tracking fruits across multiple sessions in two orchards (apples and peaches).

Active Perception using NeRFs. We have developed an information-theoretic approach for autonomous exploration, to take control actions that maximize the mutual information between the past image and future images. We argued in a paper that exploration requires (a) a representation of the scene that summarizes past observations and updates this representation using new observations (state estimation and mapping), (b) the ability to synthesize new observations of the scene (a generative model), and (c) the ability to select control trajectories that maximize predictive information (planning). This approach was demonstrated in simulated environments and in real experiments in urban environments.

TESTBED & JOINT-OP ACTIVITY

We have developed systems that enable autonomous aerial robots to navigate between trees in orchards and forests, construct metric-semantic maps and extract actionable information. Field trips have been conducted at the UC Merced testbed and forests in Virginia. The data collected in these field trips has been included in TreeScope (https://treescope.org). Treescope data and benchmarking algorithms are open-source, encouraging the forestry and agriculture communities to use it to test their own segmentation and tree diameter estimation algorithms. Our open-source autonomous navigation stack, semantic mapping algorithm, and treescope have been widely used (forked ~150 times in total on GitHub). With the Project 17/UC Merced testbed, we collected datasets using the sensor tower and UAV platforms to test our metric-semantic mapping systems.

Project Title: : 9_SEMANTIC MAPPING – Semantic Mapping of Orchards for Yield Estimation

Thrust(s): Thrust 1 – Agricultural Sensor Systems / Thrust 3 – Agricultural Response Systems ARL / TRL: 6 / 7

Faculty Investigators: Vijay Kumar, Pratik Chaudhari (Penn), Reza Ehsani (Merced), Dave Cappelleri (Purdue)

Researcher(s): Liu, Cladera, Li, Das, Ong, Shao, Prabhu, Cheng, Lei, Zhou, Li (Penn), Mortazavi, Cruz, Ruiz (Merced), Chopra (REU)

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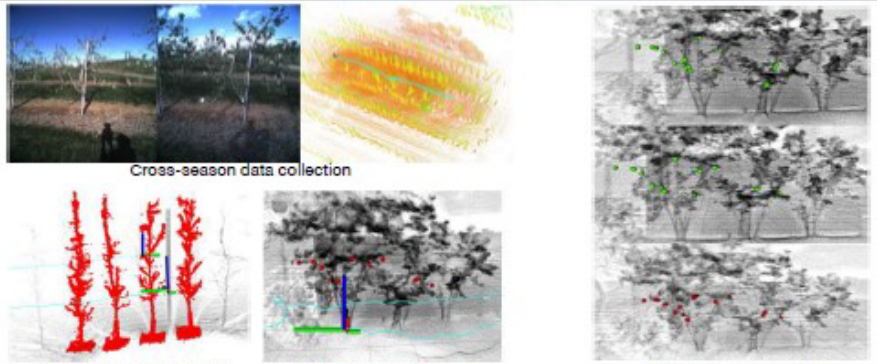
PROJECT OVERVIEW

Develop autonomous and collaborative robotic systems capable of reliably surveying large-scale agricultural environments, actively gathering high-quality actionable information, and persistently monitoring changes over time.

This project focuses on:

1. Mapping and localization systems for heterogeneous robot teams to explore 3D agricultural and forestry environments
2. Autonomous unmanned aerial vehicles (UAVs) for GPS-denied large-scale mapping tasks in orchards and forests under-canopy environments
3. Extend our systems from 3D to 4D so that the robots can persistently monitor changes over time and reliably gather accurate and actionable information

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Barriers

- Autonomous robots cannot work robustly in unstructured environments
- Heterogeneous robotic systems cannot work together
- Persistent monitoring and reliable change detection over time in orchards
- Very little data is available pertaining to agriculture

Approaches

- Scalable and robust SLAM systems for heterogeneous robots
- Event-based odometry to operate in harsh lighting and unstructured environments
- Photometric and geometric maps of steam/stalk, leaves and fruit. Estimate fruit yield using computer vision techniques.
- Develop techniques for continuous monitoring

KEY ACCOMPLISHMENTS TO-DATE

1. A real-time decentralized metric-semantic SLAM approach for heterogeneous robot teams to explore and map forests and farms.
2. Active perception techniques for mapping new environments
3. A new approach for monocular, event-based visual-inertial odometry to address harsh lighting conditions.
4. Photorealistic maps of trees and foliage from sparse views using neural radiance fields and 360-degree cameras
5. We developed an autonomous UAV system for fine-grained metric-semantic mapping in under-canopy forest environments.
6. Yield estimation and monitoring changes across time in orchards
7. TreeScope is the first semantically segmented LiDAR dataset that provides a benchmark for tree counting and mapping forestry and orchards.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 10_PATH PLANNING: Informed Path Planning for Data Collection in Orchards
Thrust(s): Thrust 1 – Agricultural Sensors Systems / Thrust 3 – Agricultural Response Systems
Lead Faculty Investigator: Stefano Carpin (Merced)
Co-Investigator(s): Reza Ehsani (Merced), Vijay Kumar (Penn)
Researcher(s): Zuzuarregui, Booth, Shamshirgaran, Mortazavi (PhD/Merced), Ng, Stewart (Undergrad/Merced), Liu, Caldera, Prabhu (PhD/Penn), Lei (Staff/Penn)

LOCATION ON 3-PLANE DIAGRAM: 2. Enabling Technology
TRL #: 6 **ARL #:** 2

OBJECTIVES & CENTER ALIGNMENT:
We study planning algorithms for single and multi-robot active information acquisition in farm environments. We are developing optimization algorithms to plan the motion of single robots and coordinate multiple robots tasked with efficiently collecting data in orchards. The algorithmic design is informed by the physical characteristics of the sensors and incorporates the constraints associated with the operating environment (e.g., operation under canopy, limited energy availability.) The objective is to compute control policies for sensing robots which minimize the accumulated uncertainty of a dynamic hidden state over an a priori unknown horizon. Now moved to the testbeds, these algorithms offer a foundation over which high level data acquisition efforts can be seamlessly integrated.
This project is related to multiple center level goals. It supports the creation of "*novel, integrated systems that capture the microclimate and spatially, temporally, and compositionally map heterogeneous stresses for early detection and intervention to better outcomes in agricultural crop production*". It is also aligned with the Thrust 1 goals, i.e., "*design and manufacture resilient, networked, intelligent sensor-robotic systems that monitor the state of plant and soil health over extended areas*."
Importantly, as the different projects matured, there is a growing interplay between projects 10, 9 and 17, as they all consider robotized data collection in orchards.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
The progress on this project advanced along two main paths. On the fundamental research front, we continued to investigate energy-aware planning, which is crucial for ensuring that robots can return to a charging station before depleting their power. Given the unpredictable nature of energy consumption, we have formally addressed this issue using stochastic orienteering and developed a family of competitive algorithms based on Monte Carlo Tree Search (MCTS). However, a limitation of MCTS is its reliance on a manually crafted heuristic for the "rollout" step, which significantly impacts the solution's quality and consumes over 90% of the computational time. To address these limitations, we explored a novel approach where, instead of manually designing a heuristic, we trained a graph neural network (GNN) to learn an effective heuristic from data. Our key finding is that with a carefully chosen GNN architecture, we can train the network to accurately predict both the quality of the path and the likelihood of violating the energy constraint. This dual prediction capability is novel and replaces the time-consuming rollout with a faster forward pass

on the trained GNN, substantially reducing planning time. We believe this innovative result will serve as the foundational planning substrate for future high-level functionalities.

To test the efficacy and robustness of the planner in real world scenarios, we used it in support of a data collection task to determine if the differential between leaf and ambient temperature can be used to estimate the stem water potential in high value perennial crops such as almonds and pistachios. This activity is synergistic with Project 17. To this end, we have integrated a thermocamera and a temperature sensor on a Husky robot and we have integrated them into the autonomous navigation stack we formerly developed as part of project 10. With this setup (see also the section Testbed & Joint Op Activity), we are testing the planner in the field, autonomously collecting data at scale. Data collected by the root is being compared with data manually collected in the orchard (see also figures in the quadchart). Cross validation of data collected manually and by the robot is ongoing and suggests the approach is scalable, although definitive conclusions will be drawn only at the end of the growing season.

In connection with Project 9, we also developed methods to build metric-semantic maps for orchards using UAVs. These semantic maps inform higher-level planners about regions of interest (such as trees and fruit locations) and areas to avoid (like ditches and roads). A crucial aspect of this research involves accounting for temporal evolution, considering how orchards change over time (e.g., growth) and seasonally (e.g., summer to winter). This has led to the exploration and testing of the concept of 4D mapping in the testbed.

TRL and ARL assessment: The key technologies developed in this project are three: algorithms for efficient planning under resource constraints; algorithms for robust navigation in agricultural environments; systems to estimate water stress in high value crops at scale (built on top of the first two key technologies).
TRL: project 10 is at TRL 5 (Technology validation in IoT4Ag-related field or testbed). As detailed below this approach is being tested weekly in the UC Merced tedbeds.
ARL: project 10 is at ARL 2 (Used by the IoT4Ag project team that conceived it). Currently the technologies developed are being used only by our team. However, if the methodology for water stress estimation proves successful, we anticipate deploying it outside our immediate team, thus moving to level 3.

TESTBED & JOINT-OP ACTIVITY:
Starting in May 2024, we have been conducting weekly field experiments in the testbeds at UC Merced, focusing on mature pistachio and almond trees. These activities are part of Joint Op 2: Integrated Systems to Optimize Water Use in Tree Crops. In line with the project's goals set at the beginning of the year, the objective is to assess whether autonomous robots, equipped with the planning algorithms we developed, can effectively scale the collection of temperature differentials between leaves and ambient air to infer stem water potential in perennial crops, with the ultimate aim of optimizing water usage. Data collected so far shows that automated data collection produces results comparable to manual methods, supporting the hypothesis that robots can efficiently gather field data valuable for optimizing water use. The rest of the summer will be dedicated to gathering additional data to refine the model that maps temperature differentials to stem water potential.

Project Title: 10_PATH PLANNING: Informed Path Planning for Data Collection in Orchards

Thrust(s): Thrust 1 / Thrust 3 **ARL / TRL:** 2 / 6

Faculty Investigators: Stefano Carpin, Reza Ehsani (Merced); Vijay Kumar (Penn)

Researcher(s): Zuzuarreui, Booth, Shamshirgaran, Mortezavi, Ng, Stewart (Merced); Liu, Caldera, Prabhu, Lei (Penn)

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PROJECT OVERVIEW

We develop planning algorithms for single and multi-robot active information acquisition in ag. This involves developing optimization algorithms to guide single robots and coordinate multiple robots in efficiently collecting orchard data. The design considers the physical characteristics of the sensors and environmental constraints (e.g., operation under canopy, limited energy). The goal is to create control policies for sensing robots that minimize the uncertainty of a dynamic hidden state over an unknown horizon. These algorithms, now in the testing phase, provide a foundation for integrating high-level data acquisition efforts.

This project supports the creation of "*novel, integrated systems that capture the microclimate and spatially, temporally, and compositionally map heterogeneous stresses for early detection and intervention to better outcomes in agricultural crop production*". It aligns with the Thrust 1 goals, i.e., "*design and manufacture resilient, networked, intelligent sensor-robotic systems that monitor the state of plant and soil health over extended areas.*"

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

- We developed energy-aware planning for robots, addressing energy consumption unpredictability with stochastic orienteering and Monte Carlo Tree Search (MCTS). To overcome MCTS limitations, we trained a graph neural network (GNN) to predict path quality and energy violations, replacing time-consuming rollouts with faster GNN predictions, significantly reducing planning time.
- We integrated a thermocamera and temperature sensor into the Husky robot's autonomous navigation system from project 10. This setup collects large-scale data to evaluate if the temperature difference between leaf and ambient air can estimate stem water potential in high-value crops. Data is cross-validated with manually collected orchard data from Project 17, showing scalable potential, with final conclusions pending season end.

KEY ACCOMPLISHMENTS TO-DATE

Accomplishments and impact:

- Technology fully integrated into UC Merced testbed operation with weekly data collection in support of Joint Ops 2 (Optimize Water Use in Tree Crops)
- Strengthened connections with projects 9 and 17
- Published 5 papers at leading international robotics venue (more under review)
- Working on one invention disclosure for the resource constrained path planning algorithm

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 11_CLUTTERED ENVIRONMENTS: Wireless Charging of Electronics in Cluttered Environments
Thrust(s): Thrust 2_Communication and Energy Systems
Lead Faculty Investigator: David Arnold (Florida)
Co-Investigator(s): William Eisenstadt (Florida)
Researcher(s): Crasto (PhD /Florida), Stormant (Undergrad/Florida)

LOCATION ON 3-PLANE DIAGRAM: 2. Enabling Technologies (energy devices)
TRL #: 4 **ARL #:** 2

OBJECTIVES & CENTER ALIGNMENT:

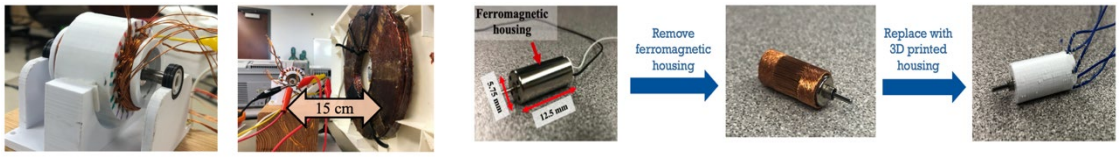
- KEY OBJECTIVES OF THIS PROJECT: The key objective of this project is to enable new technologies to facilitate recharging of power sources (i.e., batteries) or powering battery-less sensors in a cluttered environment. For example, we are designing a system for transmitting power wirelessly to recharge the batteries integrated with a sensor and a transceiver system located below the soil surface. Conventional WPT systems (i.e., inductive) utilize high-frequency (kHz-MHz range) magnetic fields that restrict efficient/effective power transfer to longer distances, especially while transmitting through conductive media, such as soil. Our approaches mainly utilize low-frequency (below 1 kHz) magnetic near-fields to potentially overcome such issues.
- With this work, we are aligning with the research goals of Thrust 2 of powering IoT devices and data communication modules from heterogeneous platforms of sensors, robots, and farming equipment.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

- A custom built electrodynamic wireless power transfer (EWPT) receiver using a one-inch diameter cylindrical permanent magnet was developed and tested for low-frequency wireless power transfer. This device uses low-audio frequencies (< 1 kHz) rather than RF frequencies. This prototype demonstrates a power transfer of 10 W at 10 cm with an efficiency of 72% up to 975 mW at 30 cm with an efficiency of 7%. A normalized power density of 247 $mW/cm^3/mT^2$ was achieved (double all previously reported similar systems). The efficiencies of this novel concept and the power transfer distances are state-of-the-art for a coil-based transmitter [1].
- As an alternative and economically viable option, an off-the-shelf coreless DC motor was converted into an EWPT receiver by replacing the stainless-steel housing with a 3D printed housing. This receiver with its superior commercially winding design, transferred power from 106 mW at 12 cm to 15 mW at 30 cm. At 30 cm, the corresponding normalized power density was 509 $mW/cm^3 \cdot mT^2$, the highest reported value [2].
- The miniature EWPT receiver was used to compare power transfer using two transmitters, a current carrying coil and a rotating magnet transmitter. For a given field amplitude at 12

cm, the rotating magnet transmitter outperformed the current carrying coil transmitter with 2.4 times higher power output [3].

- An intermediate sized receiver with a 5/8" diameter cylindrical permanent magnet and three phase winding was designed, assembled and characterized. This receiver along with the coil transmitter was used to demonstrated power a soil moisture sensor. The setup also included a battery management system, rechargeable batteries and an ESP 8266 Wi-Fi SoC, all buried beneath a 13 cm layer of topsoil to demonstrate power transfer to a buried sensor system [4]. In this work, the three-phase receiver was demonstrated to recharge a 3.7 V battery in 43 minutes.



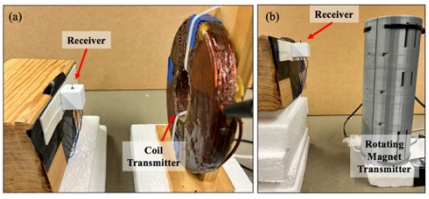


*Figure SEQ Figure * ARABIC 3: The miniature receiver driven with a rotating magnet transmitter proved to be more efficient than current*

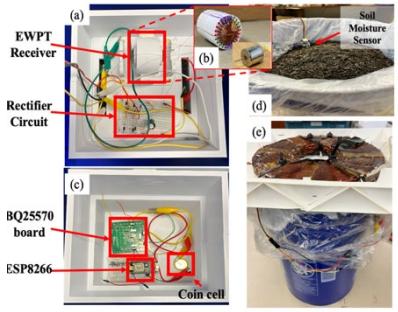


*Figure SEQ Figure * ARABIC 4: A custom built EWPT receiver was used to power a soil*

TESTBED & JOINT-OP ACTIVITY:

- With the current power transfer milestones and the successful demonstration of WPT of a buried sensor system, we intend to replace the power-hungry Wi-Fi with LoRaWAN (from William Eisenstadt's group) and work with Ian Small to deploy these receivers to power NPK sensors, at the UF NFREC testbeds during Year 5 with the goal of optimizing Nitrogen (Joint-Ops 1).
- The deployment will involve mounting the transmitter, either a coil or rotating magnet driven by a dc motor, at the lower end of the irrigation system. This placement allows the transmitter to power the receivers as it passes over them during regular irrigation cycles. The receiver(s), buried 30-50 cm beneath the soil, will be optimized to recharge their batteries during the brief 'dwell times' when the transmitter is directly overhead. This optimization will focus on reducing the necessary recharging time, ensuring that the system can efficiently power NPK sensors even with limited exposure to the transmitter. The deployment scenario will be tested in the field at UF NFREC testbeds, where we will assess the effectiveness of the power transfer in various soil conditions and distances. On the WPT front, backscatter communication from the EWPT receiver will also be explored to provide information on the status (on/off) of the receiver beneath the soil. The ultimate goal is to achieve reliable, wireless power for NPK sensors to optimize nitrogen usage in precision agriculture.

Project Title: 11_CLUTTERED ENVIRONMENTS/ Wireless Charging of Electronics in Cluttered Environments

Thrust(s): Thrust 2 **ARL / TRL:** 2 / 4

Faculty Investigators: David Arnold, Bill Eisenstadt (Florida)

Researcher(s): Crasto, Stormant (Florida)

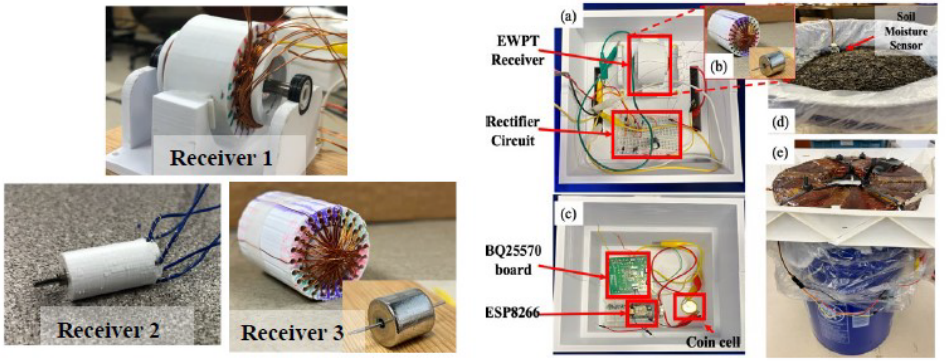
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PROJECT OVERVIEW

The key objective is to transmit power wirelessly to recharge batteries that are integrated with a sensor and a transceiver system placed at sub-surfaces. Conventional Wireless Power Transfer (WPT) systems utilize high-frequency (kHz~ MHz range) magnetic fields that restrict efficient/effective power transfer to longer distances, especially while transmitting through conductive media. Our approaches mainly utilize low-frequency magnetic near-fields to potentially overcome such issues.

Our efforts are on leveraging this concept and providing uninterrupted power for devices developed by our partner groups. With this, we are aligning with the research goals of Thrust 2 of powering IoT devices and data communication from heterogenous platforms of sensors, robots and farming equipment.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

- Leveraging our low-frequency WPT system to power a buried sensor system.
- With the current power transfer milestones and having demonstrated power transfer to a buried system, we intend to replace Wi-Fi (existing) with LoRaWAN devices and work towards deploying these devices at the UF NFREC testbeds during Year 5 with the goal of optimizing Nitrogen (Joint-Ops).

KEY ACCOMPLISHMENTS TO-DATE

- Rotating magnet receivers of three different sizes have been demonstrated power transfers of up to 30 cm with superior normalized power densities..
- Receiver with a 5/8" diameter cylindrical permanent magnet was used to power a buried soil moisture sensor systema and a Wi-Fi communication module via a battery management system.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 12_ROBOT POWER: Autonomous Wireless Charging of Drones
Thrust(s): Thrust 2 – Communication and Energy System / Thrust 1 – Agricultural Senor Systems
Lead Faculty Investigator: Sue Ann Bidstrup Allen (Penn)
Co-Investigator(s): Mark Allen (Penn), David Arnold (Florida)
Researcher(s): Huang (PhD/Penn), Lyu (MS/Penn), Mody, Fluker (REU/Penn), Cruz (RET/Penn), Free (PhD/Florida) Bian (Undergrad/Florida)

LOCATION ON 3-PLANE DIAGRAM: 2. Enabling technology

TRL # 5 **ARL #** 3

OBJECTIVES & CENTER ALIGNMENT:
Precision agriculture requires agricultural drones to cover large areas for crop inspection and sensor interrogation. The information collected by the agricultural drone is then processed and helps end-users achieve precision agriculture. The efficiency of data collection heavily depends on the flight duration of the agricultural drone. However, the flight duration of current agricultural drones is usually restricted due to the limited energy density of lithium-ion batteries (LIBs) used in drones. To address this challenge, our research will center on the development of high-energy aluminum-air batteries (AABs) specifically engineered for agricultural drones. AABs possess a theoretical gravimetric energy that surpasses that of LIBs by an order of magnitude, presenting the potential to significantly extend the flight duration of agricultural drones. Therefore, this promising technology can significantly enhance the data collection efficiency of agricultural drones in precision agriculture.

For ground robots, we propose that power can be distributed to robots in a more efficient manner that properly aligns with and facilitates IoT4Ag's mission of improving automation and autonomy for farming equipment. Currently, robots are used sparingly due to the tendency of these robots to require being plugged in by a human to charge, making them limited to doing things humans can already do. The ability for robots and drones to be able to recharge themselves is crucial for them to really perform duties better than humans. By allowing for robots - both on the ground and in the air – that can recharge without the need for human interaction, the robots and the operations they perform can be integrated into a true Internet of Things environment.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
In YR4, high-energy-density and high-power-density AABs are developed to power centimeter-scale quadrotors. Initially, a low-package overhead AAB fabrication technique is developed, resulting in the battery package contributing only 9% of the total cell weight, compared to over 30% in equivalent commercial LIBs. Additionally, the anode and electrolyte of the AABs are engineered to achieve an energy density of 320 Wh/kg above a power density of 500 W/kg, significantly outperforming commercial LIBs. A customized 3D-printed small-scale quadrotor platform is employed to evaluate flight duration, with the AABs delivering 13.1 minutes of flight time compared to the 4.5 minutes provided by commercial LIBs. To our knowledge, this marks

the first successful attempt at untethered powering of a quadrotor using air batteries. However, achieving the required power for the quadrotor necessitates using an expensive Pt-based cathode, which accounts for over 99% of the AAB cost. To address this cost issue, cost-effective high-power Ag-based cathodes are investigated. Through microfabrication, the power performance of the Ag-based cathode is enhanced by increasing its electrochemically active surface area. This cathode supports the necessary power density for the small-scale quadrotor while potentially reducing costs to 1/1500th of that of conventional cathodes. This work highlights the potential of AABs to serve as efficient, cost-effective, and long-lasting power sources for small-scale quadrotors.

Another method for providing robots with efficient energy is a module which allows capable robots to charge their batteries without human intervention. In this pursuit, two prototypes were developed using two different off-the-shelf battery management systems to ensure the safe recharging of the batteries internal to robots. With these prototypes, the charge rate was determined to match that of the provided, wired charger, which operates at the maximum safe charge rate of the battery. Intrinsically, the efficiency for a wireless system is worse than that of a wired connection, but the wireless systems are completely enclosed and isolated from one another, which enables use in an outdoor environment, such as an agricultural field. A custom PCB was developed to simplify the system for the user. This PCB combines a streamlined battery management system, and an easily programmable microprocessor so that electrical characteristics like charge rate and safety features such as maximum temperature can be easily controlled. Iteration has also been key to improving the physical design of the enclosures for both the wireless power transmitter and receiver. A novel “backpack” model has been developed that is both accessible to farmers and low-cost to produce and apply. This design choice enables the wireless charging module to be easily applied to robots already used throughout IoT4Ag, such as the Jackal UGV. In combination with new battery chemistries, autonomous charging can aid in pursuit of greater uptime in both robots and drones in agricultural settings.

TESTBED & JOINT-OP ACTIVITY:

In YR 4, the performance of AABs is evaluated using a commercial drone platform as the testbed for this project. Through performance characterization of the AABs, we identify a suitable centimeter-scale quadrotor platform that can potentially function in the agricultural environments of interest. In the long-term, this integrated system can be deployed in both row crops testbeds and tree crops testbeds.

Project Title: 12_ROBOT POWER: Autonomous Wireless Charging of Drones

Thrust(s): Thrust 2 / Thrust 1

ARL / TRL: 3 / 5

Faculty Investigators: Sue Ann Bidstrup Allen (Penn), Mark Allen (Penn), David Arnold (Florida)

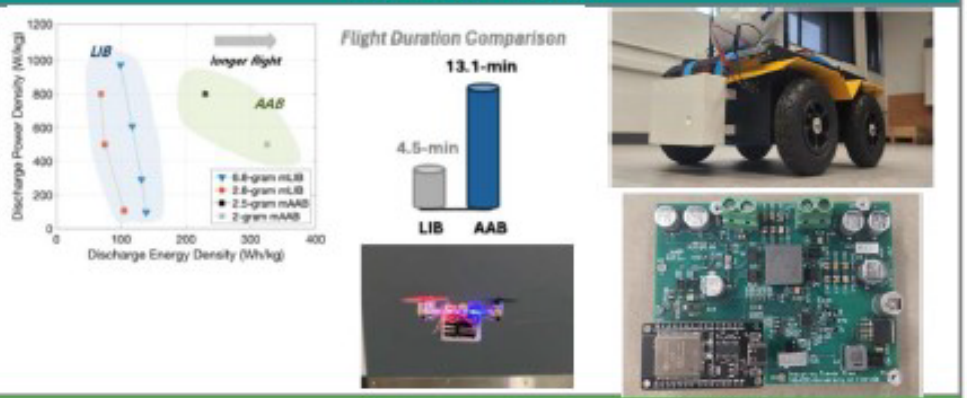
Researcher(s): Huang, Lyu (Penn), Mody, Fluker (REU), Cruz (RET), Free, Bian (Florida)

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PROJECT OVERVIEW

Precision agriculture requires agricultural drones to cover large areas for crop inspection and sensor interrogation. The efficiency of data collection heavily depends on the flight duration of the agricultural drone. However, the flight duration of current agricultural drones is usually restricted due to the limited energy density of lithium-ion batteries (LIBs) used in drones. To address this challenge, our research will center on the development of high-energy aluminum-air batteries (AABs) for extended operation of agricultural drones. Our research will also focus on improving the usability of LIBs through improved rechargeability methods. By adding the ability for robots and drones to be charge themselves through a proximity-based wireless charging method, these tools can be used autonomously. Autonomy is necessary for agricultural robots and drones to be integrated into an Internet of Things environment to be free of human intervention.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

The current quadrotor platform employs the propulsion system (motors and propellers) and circuitry from the off-the-shelf quadrotor, which are optimized for the best compatibility with commercial LIBs. Developing a quadrotor platform that is more compatible with AABs is promising for further extending the flight duration. For ground robots, we introduce a retrofit module that facilitates wireless charging with no internal modifications.

Scaling up the current AAB battery technology for larger-scale drone applications (e.g., drones weighing tens of kilograms) presents potential challenges due to the potential loss of power performance as the AAB scales up. The wireless charging module presents a challenge of generalizing to be able to adapt to any model of robot with different physical and electrical characteristics.

KEY ACCOMPLISHMENTS TO-DATE

- Developed AABs with energy density of 320 Wh/kg, significantly surpassing the performance of equivalent commercial LIBs.
- Demonstrated the untethered flight of AAB-powered centimeter-scale quadrotors, achieving a flight duration of 13.1 minutes, much higher than the 4.5 minutes flight powered by commercial LIBs.
- Developed a cost-effective high-power Al-air battery cathode that potentially reduce AAB cost by 1500 times.
- Developed a prototype retrofitting wireless charging module that can be applied to existing robots, allowing them to charge with no wired connection.
- Developed a custom PCB that facilitates customization of charging characteristics for various robot batteries.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 16_AG COMM: Communication to Enable Agricultural Sensing
Thrust(s): Thrust 2 – Communication and Energy Systems
Lead Faculty Investigator: David Love (Purdue)
Co-Investigator(s): Jim Krogmeier, Dennis Buckmaster (Purdue), Bill Eisenstadt, David Arnold, Ian Small (Florida)
Researcher(s): Lee, Natraj Arun, Castiblanco Rubio, Iboyi, Malayter, Barocco (PhD/Purdue)

LOCATION ON 3-PLANE DIAGRAM: 1. Fundamental Knowledge / 2. Enabling Technology
TRL #: 1 (ISAC4Ag), 1 (Backhaul), 1 (LPWAN)
ARL #: 1 (ISAC4Ag), 1 (Backhaul), 1 (LPWAN)

OBJECTIVES & CENTER ALIGNMENT:
Advanced sensing and farming systems require high-rate connections, but they are usually located in regions with little to no broadband coverage. We aim to design and analyze communication systems for rural agricultural sites. These communication systems must take into account the unique constraints (e.g., latency and security) that are required for the agricultural use case. Another objective is to characterize the fundamental limits (e.g., coverage predictions, capacity, etc.) of communication networks for use in future work and in other thrusts. This project aligns well with IoT4Ag objectives. Communication is key to integrating sensing and autonomy developments into real-world systems.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

- **Approach in Year 1:** We performed analysis of wireless coverage in rural areas across the United States by using propagation modeling and publicly available data. We performed research on secure communications and multi-hop relaying.
- **Approach in Year 2:** We continued our work to characterize the state of wireless coverage in rural areas within the United States and to develop/analyze communication algorithms for the agricultural use case. We also have made progress and continued to work on developing a framework that allows us to show rate improvements as a function of capital investments (e.g., access points). This is essential for designing signal processing algorithms for terrestrial multi-hop relaying.
- **Approach in Year 3:** We have continued our work on designing wireless backhaul architecture for rural agriculture, making progress in duplexing schemes with a cross-layer design and computing throughput improvements relative to capital investment. Additionally, we have begun using RFID as a wireless communication channel to read underground sensor data, integrating RFID readers and antennas with our OATSMobile hub, ISOBlue, and Avena to streamline data collection based on different drainage classes in the IoT4Ag field at ACRE.
- **Approach in Year 4:** We have continued our existing work on designing wireless backhaul architecture for a rural agriculture scenario. We focused on designing low power wide area networks imperative to sensors deployed in agricultural farms. We focused on a multi-cell scenario which is interference limiting in existing networks and proposed a new scheme to eliminate the interference. Apart from that, we have continued our work on modeling the

wireless channel which is important to understand wireless backscatter communications. Also, in Year 4, we investigated the problem of designing ISAC waveforms that accomplish radar sensing and communication tasks simultaneously using a single transmitter. Our research focused on improving sensing resolution of the waveform, while serving communication nodes.

ACCOMPLISHMENTS AND IMPACT:

- The OATSMobile, integrated with ISOBlue and Avena, automates data collection and remote sensing using 4G-LTE, Wi-Fi, and LoRaWAN, and includes RFID readers for buried sensor data.
- Avena is an open-source framework that facilitates sensor fusion and data transfer from agricultural machinery using LTE, 5G-NR, LoRaWAN, and other radio technologies.
- In Year 3, Avena enhanced its capabilities to support diverse data streams, such as IP cameras and Lidar sensors, improving data collection and transfer to the cloud.
- Multi-hop backhaul communication networks were studied to improve plant and soil monitoring, with notable publications in IEEE Transactions on Wireless Communications and IEEE Transactions on Information Theory.
- A new scheme for LPWANs eliminates inter-cell interfereA nce, optimizing uplink transmissions from agricultural sensors, with findings published in IEEE Wireless Communication Letters.
- Research in Year 4 on Dual Function Radar and Communication (DFRC) developed ISAC waveforms for simultaneous radar sensing and communication, enhancing applications like crop monitoring and weather forecasting.
- In year four, we developed machine learning-based channel models for rural communications, with our findings published in IEEE ICC 2024.
- Satellite and non-terrestrial communication were studied and analyzed in year four, with the results published in IEEE Transactions on Aerospace and Electronic Systems and IEEE Journal on Selected Areas in Communication.

TESTBED & JOINT-OP ACTIVITY:

- We have been extensively using ACRE to run our underground communication experiments in scale after lab testing. This includes planting RFID sensors, planting soil moisture sensors, designing and building OATSMobile and adding support on Avena to interface with RFID readers
- LoRaWAN radios were sent to the University of Florida's testbed to bring up all the sensors under the Avena network to have a unified backhaul communication channel for sensors.
- A LoRaWAN system was installed in the Quincy, FL, University of Florida Testbed.

INDUSTRY ENGAGEMENT:

Professor David Love and Professor James Krogmeier have been actively participating in defining the key performance indicators (KPIs) for 6G precision agriculture with the Next G Alliance. They have given presentations to the ATIS Next G Alliance, highlighting the impact of 6G on precision agriculture. Prof. William Eisenstadt transferred LoRaWAN technology to Pure BioMass, an IoT4Ag Center member company.

Project Title: 16_AG COMM: Communication to Enable Agricultural Sensing

Thrust(s): Thrust 2 **ARL / TRL:** 1 (ISAC4Ag), 1 (Backhaul), 1 (LPWAN)/ 1 (ISAC4Ag), 1 (Backhaul), 1 (LPWAN)

Faculty Investigators: David Love, James Krogmeier, Dennis Buckmaster (Purdue), David Arnold, Ian Small, William Eisenstadt (UF)

Researcher(s): Lee, Natraj Arun, Castiblanco Rubio, Iboyi, Malayter, Barocco (Purdue)

IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

PROJECT OVERVIEW

Advanced sensing and farming systems require high-rate connections, but they are usually located in regions with little to no broadband coverage. We aim to design and analyze communication systems for rural agricultural sites. These communication systems must take into account the unique constraints (e.g., latency and security) that are required for the agricultural use case. Another objective is to characterize the fundamental limits (e.g., coverage predictions, capacity, etc.) of communication networks for use in future work and in other thrusts. This project aligns well with IoT4Ag objectives. Communications is key to integrating sensing and autonomy developments into real-world systems.

SUMMARY FIGURE

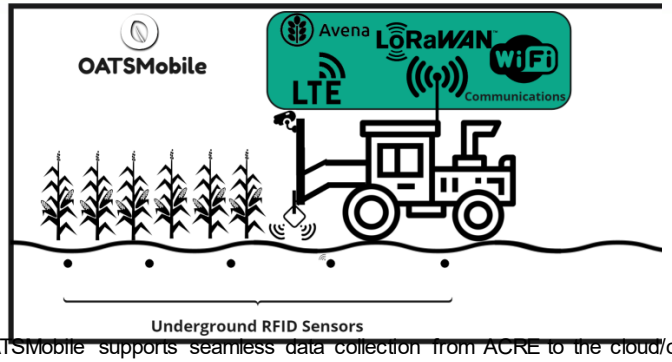


Figure: OATSMobile supports seamless data collection from ACRE to the cloud/offsite using the communication modules and the Avena platform

RESEARCH APPROACH & BARRIERS

Approach in Year 4: *We continued our work on designing wireless backhaul architecture for rural agriculture, focusing on low power wide area networks for farm sensors. We addressed interference in multi-cell scenarios and proposed a new scheme for its elimination. Additionally, we modeled the wireless channel for backscatter communications. In Year 4, we designed ISAC waveforms to perform radar sensing and communication simultaneously, aiming to improve sensing resolution while serving communication nodes.*

Testbed and Joint-Ops Activity *We have been extensively using ACRE to run our underground communication experiments in scale after lab testing, including planting RFID sensors, planting soil moisture sensors, designing and building OATSMobile and adding support on Avena to interface with RFID readers. LoRaWAN radios were sent to the University of Florida's testbed to bring up all the sensors under the Avena network to have a unified backhaul communication channel for sensors.*

Barriers *There is very little prior work on the agricultural use case for communication. To work around this, we will map agricultural constraints to those found in commercial urban/suburban deployments and government use cases.*

KEY ACCOMPLISHMENTS TO-DATE

OATSMOBILE for backhaul communication *We successfully developed and implemented a mobile data hub, called the OATSMobile, to automate data collection and remote sensing at ACRE. OATSMobile can collect and transfer data to the external server through ISOBlue/Avena.*

Relay communication *We developed and analyzed low-latency relaying networks for backhaul communication and designed novel precoders for in-band full-duplex relaying. These advancements improve the efficiency and performance of backhaul communication networks.*

Rural channel modelling *We extensively studied wireless propagation in rural areas to aid in modeling the wireless channel. These insights are crucial for developing accurate and reliable communication systems tailored to rural environments.*

Avena for agricultural backhaul communication *Avena played an essential role in collecting and transferring data from OATSMobile to the cloud via LTE and Wi-Fi. Furthermore, Avena has evolved to support diverse streams such as IP cameras, mesh Wi-Fi, Lidar sensors, and RFID readers.*

ISAC and LPWAN : *A new scheme for LPWANs eliminates inter-cell interference, optimizing uplink transmissions from agricultural sensors. In Year 4, research on Dual Function Radar and Communication (DFRC) developed ISAC waveforms for simultaneous radar sensing and communication, enhancing applications like crop monitoring and weather forecasting, with findings published in the IEEEICC 2024.*

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 17_ORCHARD: Developing Technology for Detecting Tree-Specific Water Stress in an Orchard
Thrust(s): Thrust 1_Agricultural Sensors Systems / Thrust 3 – Agricultural Response Systems
Lead Faculty Investigator: Reza Ehsani (Merced)
Co-Investigator(s): Stefano Carpin (Merced)
Researcher(s): Mortazavi, Alizadeh (PhD/Merced), Toudeshki (Staff/Merced), Cruz, Ruiz (Undergrad/Merced)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems (Integration)
TRL #: 6 **ARL #:** 3

OBJECTIVES & CENTER ALIGNMENT:
This project was established to develop a technology to find a better alternative solution for monitoring water stress, particularly in predicting tree-specific stem water potential. Various sensors have been deployed and tested on the UC Merced testbed throughout the past four years. It started with developing a model-based tree-specific water stress detection that utilized a series of easy-to-collect spatial data sets and AI models. This model was able to classify stressed trees with high accuracy. While this approach was successful, we tried to investigate an even more straightforward approach. In 2024, we developed a cost-effective and easy-to-use sensor to measure leaf water content. Developing technology for fast and cost-effective detection of tree-specific water stress can help growers improve water use efficiency by improving irrigation schedules and simplifying applying techniques such as deficit irrigation.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

We applied machine learning (ML) to data collected from UAV-based aerial images, local weather and sensor data to predict stem water potential (SWP) in pistachio and almond trees, addressing the inefficiency of traditional pressure chamber methods. By combining weather, thermal, and multi-band aerial imaging, we tested six supervised ML classification models: Random Forest (RF), Support Vector Machine (SVM), Gaussian Naive Bayes (GNB), Decision Tree (DT), K-Nearest Neighbors (KNN), and Artificial Neural Network (ANN). All classification models achieved over 79% accuracy, with RF performing best at 88% for pistachios and 89% for almonds. The RF model revealed that the weather features were the most influential factors in the decision-making process. In both crops, canopy temperature T_c was the next important feature, closely followed by OSAVI in pistachios and NDVI in almonds. In 2024, we incorporated multiple season data into our model. Our classification model based on three classes (no stress, medium stress, high stress) was improved, achieving a prediction accuracy of 90-92 percent. These results demonstrate the success of our approach in tackling problems associated with identifying water stress in orchards.

In addition to model-based water stress detection, we have developed a new sensor called Water Stress Sensor Clip (WSSC) to measure the leaf's water content. Two versions of this sensor were developed. In the first version (Fig-1)., the sensor was able to measure the leaf water content after

the leaf was removed from the tree. The second version was a much smaller sensor that could be attached to the leaf on the tree and measure its water content without removing it from the tree. The prototype sensor has self-data storage and a display that provides data and other information to the operator to make sure that data is correctly recorded and compared with the readings of the standard pressure chamber. During the 2024 growing season, from late May to the last week of September, we collect data using the standard stem water potential method and our new sensor. We plan to verify the correlation between our sensor and data from the pressure chamber to see if our sensor can predict stem water potential. Initial results are encouraging and indicate that the new sensor could be a fast and low-cost alternative to a pressure chamber for predicting stem water potential, which is critical for irrigation scheduling. In addition, a collaborative effort was started to link Project 9 _Semantic Mapping with this project. The idea was to develop a digital twin of the orchard using the sensor tower and the model developed in this project to predict water stress levels.



Figure 1-Data collection with prototype version of Water Stress Sensor Clip and pressure chamber to measure stem water potential

Sometimes, a plant's showing of water stress is not caused by lack of water; rather, it could be a sign of a disease that prevents water availability to the plant. To address this issue and to determine the exact cause of water stress, we initiated another effort to collect leaf-level visible-NIR spectral data using an autonomous platform and robotic arm. This is particularly needed when we see a small number of trees showing signs of water stress in an orchard while the other trees don't have signs of water stress. We worked on a new robotic platform for the autonomous collection of proximal spectral sensing of tree leaves. Collecting leaf-level VIS-NIR spectra provides in-depth and high-resolution information about the plant's health and water needs. Our new system benefits from a compact design suitable for field deployment. This system is currently designed to be tested in a pistachio orchard. However, we have used citrus and Magnolia in our lab testing, which have leaf shapes similar to pistachios. The current success rate of the system is 66%.

TESTBED & JOINT-OP ACTIVITY:

This project is already being field-tested at the UC Merced test sites. There, we have collected a significant amount of data for different parts of this project.

Project Title: 17_ORCHARD: Developing technology for detecting tree-specific water stress in an orchard

Thrust(s): Thrust 1 – Agricultural Sensors Systems / Thrust 3 – Agricultural Response Systems **ARL / TRL:** 3 / 6

Faculty Investigators: Reza Ehsani, Stefano Carpin (Merced)

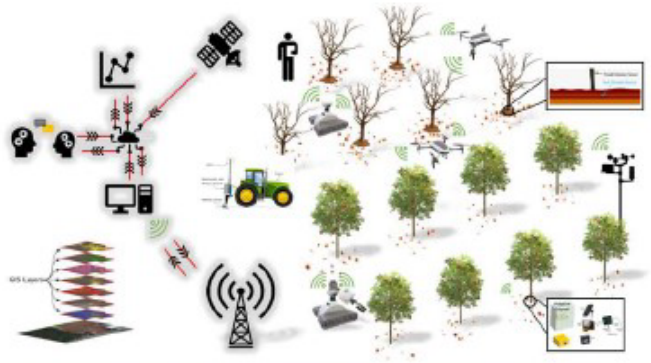
Researcher(s): Mortazavi, Alizadeh, Toudeshki, Cruz, Ruiz (Merced)

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PROJECT OVERVIEW

The research project aims to develop an IoT infrastructure for monitoring water stress, specifically predicting stem water potential. Selected as a focus project at Joint-Op 2, it has involved deploying, testing, and data collection from various sensors at the UC Merced testbed over the past four years to find an alternative approach for water stress detection, particularly the goal was to find a cost-effective way of determining stem water potential for each tree in an orchard and use that information for better irrigation scheduling that helps with improving water use efficiency

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Initially, the project focused on a model-based approach for tree-specific water stress detection, utilizing easy-to-collect datasets and AI models. Despite its success, the team sought a more straightforward solution and developed a leaf water content sensor prototype in 2024. Concurrently, another project began to gather leaf-level visible-NIR spectral data using an autonomous platform and robotic arm. The goal is to measure other biotic and abiotic stress, recognizing that water stress can result from biotic factors like bacterial diseases. Identifying the exact cause of water stress is very beneficial to growers. Potential barriers include the ability to address the complexity of measuring multiple stress factors simultaneously and developing a cost-effective approach to ensure growers adopt the new technology and integrate it into their operations

KEY ACCOMPLISHMENTS TO-DATE

Developed ML models predicting tree water status with 90% classification accuracy.

A prototype of a sensor (Water Stress Sensor Clip) for measuring the water content of leaves was developed and evaluated at the test site.

A new robotic system capable of measuring hyperspectral data in the visible and NIR ranges has been developed to collect leaf-level spectral data.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 18_SENTINEL: Sensor-based field scouting and plant health monitoring system
Thrust(s): Thrust 1 – Agricultural Sensor Systems / Thrust 3 – Agricultural Response Systems
Lead Faculty Investigator: Ian Small (UF)
Co-Investigator(s): David Arnold, Bill Eisenstadt, Alina Zare (UF), Cherie Kagan (Penn), Dave Cappelleri (Purdue)
Researcher(s): Hampton, Barocco (PhD/UF), Fandrich (MS/UF), Moore (Undergrad/UF), Teng (Staff/UF), Mallavarpu (PD/Penn)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems
TRL #: 3 – Proof of concept/critical function demonstrated via experiments and/or modeling
ARL #: 1 – Conceived by the IoT4Ag project team
OBJECTIVES & CENTER ALIGNMENT: The goal of Sentinel is to develop integrated systems using proximal and remote sensing to monitor plant health and development and to detect the symptoms and causal agents of abiotic disorders and biotic diseases. Monitoring sensors and AI detection models are being utilized or developed to augment or improve the efficiency of conventional data collection for crop models and decision support systems in project 32 (Figure 1). Sentinel projects involve developing novel sensors where there are technological gaps as well as developing novel uses of currently available technology.

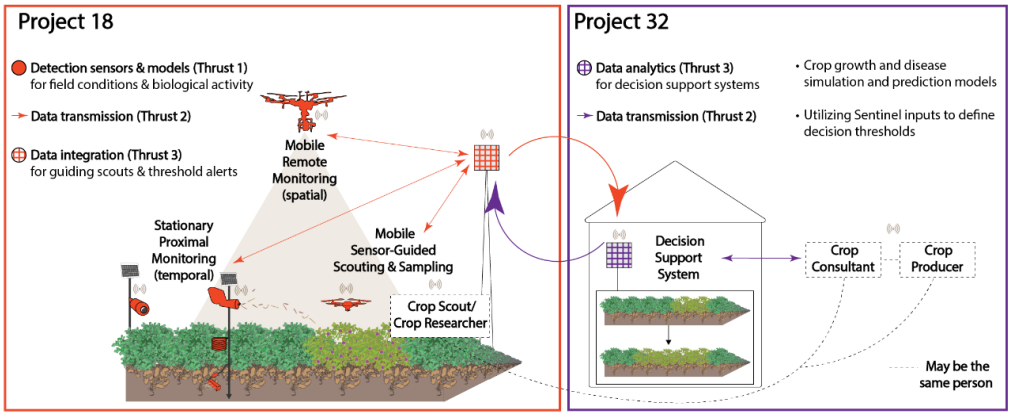


Figure 1. Diagram showing the connection of projects 18 and 32 for peanut.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

- Submitted a provisional patent application for an agricultural drone port for mobile remote monitoring.
- Demonstrated a waterproof, field-testable stationary sentinel for observing crops and the field environment with 3D AI-imaging, LoRaWAN, WiFi and solar power.
- The manuscript "Sensor-Based Quantification of Peanut Disease Defoliation Using an Unmanned Aircraft System and Multispectral Imagery" was published (https://apsjournals.apsnet.org/doi/10.1094/PDIS-05-23-0847-RE).
- Trained cotton disease AI-image detection models and automated training workflows for use on the stationary sentinel and other edge computers in the field.
- Multiple instance regression models using the MI-ClusterRegress algorithm were trained on point spectra obtained from cotton nitrogen trial plants.

TESTBED & JOINT-OP ACTIVITY:

Peanut and Cotton Diseases: These sub-projects contribute to Joint Op 3. The UAS remote sensing model for peanut disease defoliation was used to quantify disease severity in summer field trials with imagery collected by the industry liaison AgriBugs. For work on pathogen detection, Akhila Mallavarapu (PI: Kagan) fabricated gold nanoparticle substrates to enhance the Raman spectral signatures of spores for potential pathogen ID. However, the Raman microscope at the NFREC in Quincy was recently found to be defective, so Rebecca Barocco (PI: Small) followed training procedures to use the equipment at the UF main campus in Gainesville (https://rsc.aux.eng.ufl.edu/ccb/resource.asp?id=47).

Stationary Sentinel: In Fall 2023, UF Seniors created a Stationary Sentinel prototype with an E-ink display for reading in full sun, autofocus cameras and a fast Photon 2 processor with dual band WiFi. In Spring 2024, UF Seniors upgraded the Sentinel for 20x faster AI by installing a Jetson Orin processor, added stereo cameras for plant grown measurements and LoRaWAN communications. Gunnar Fandrich trained the students on the stationary sentinel software and assisted in model development for the stationary sentinel. Zihuan Teng developed and fine-tuned YOLO models specifically designed for detecting plant diseases while ensuring high accuracy and efficiency. The entire training workflow was automated, starting with setting up the training environment. This included configuring software and hardware components to optimize performance and managing resource allocation. SAM (Segment Anything Models) models were used for data labeling and annotating images of specific cotton plant diseases to create a robust training dataset. The trained models can be integrated into other sentinel systems for detecting plant diseases.

Cotton Nitrogen: This sub-project contributes to Joint Op 1. Variable rate nitrogen trials were conducted in the 2023 summer season. Petiole samples were taken every week for 5 weeks (Figure 2) paired with spectral samples. Nutrient analysis was done on a plot level (implying plot level ground truth values for nitrate), whereas leaf level spectral samples were taken on 10 plants within a plot. The spectral samples include the entire hyperspectral signal from blue visible light to short wave infrared (approximately 900 wavelengths). The goal is to correlate the spectra with the leaf level nitrate. Model predictions of plot level nitrate using bag averages (R^2 = 0.61, RMSE = 1670.87 PPM) performed better than not bagging (R^2 = 0.34, RMSE = 2157.82 PPM) (Figure 3).

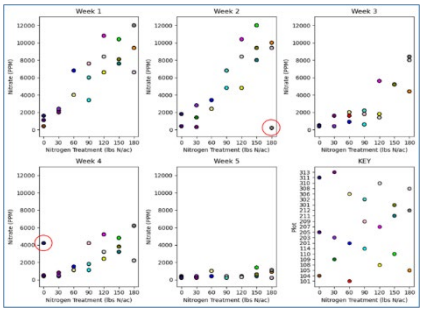


Figure 2. Visualization of nitrate levels in petiole samples over time by plot. Outlier plots are indicated by a red outline.

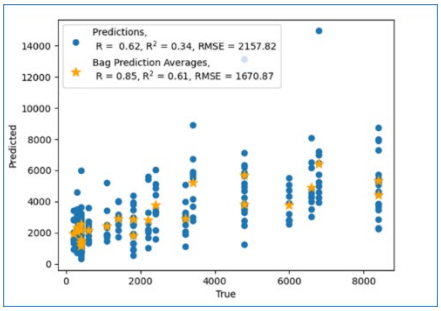


Figure 3. Nitrate level (PPM) of true observed values vs model predictions.

Project Title: 18_Sentinel: Sensor-based field scouting and plant health monitoring system

Thrust(s): Thrusts 1 / Thrust 3 **ARL / TRL:** 1 / 3

Faculty Investigators: Small, Arnold, Eisenstadt, Zare (Florida), Kagan (Penn), Cappelleri (Purdue)

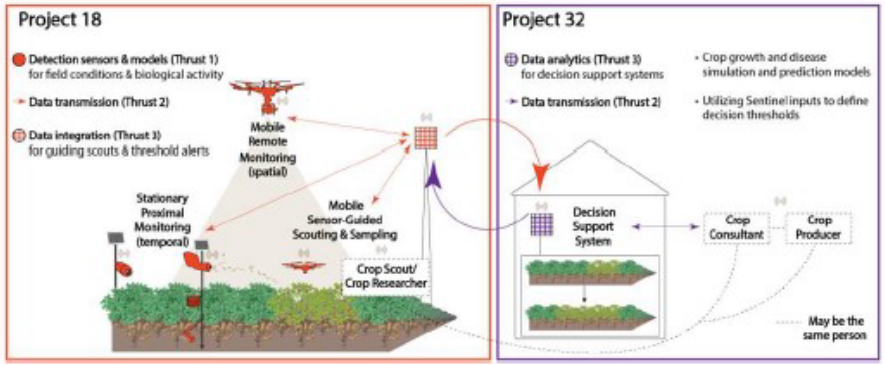
Researcher(s): Hampton, Barocco, Fandrich, Moore, Steinhauser, Teng (Florida), Mallavarpu (Penn)

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PROJECT OVERVIEW

The goal of Sentinel is to develop integrated systems using proximal and remote sensing to monitor plant health and development and to detect the symptoms and causal agents of abiotic disorders and biotic diseases. Monitoring sensors and AI detection models are being utilized or developed to augment or improve the efficiency of conventional data collection for crop models and decision support systems in Project 32. Sentinel projects involve developing novel sensors where there are technological gaps as well as developing novel uses of currently available technology.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

- Sentinel drone port: Continued development of a drone port for autonomous remote monitoring
- Stationary Sentinel: Built and field-tested AI-imaging and environmental sensor platforms for wirelessly reporting plant disease and growth data.
- Cotton Nitrogen: This sub-project contributes to Joint Op 1. Variable rate nitrogen trials were conducted in the 2023 summer season. Leaf petiole samples were taken every week for 5 weeks paired with spectral samples.
- Peanut and Cotton Diseases: This sub-project contributes to Joint Op 3. Field trials were used to develop a remote sensing model for quantifying peanut disease defoliation using multispectral imagery. A YOLO model was developed for cotton disease symptom detection, using SAM models for precise data labeling.

KEY ACCOMPLISHMENTS TO-DATE

- Submitted a provisional patent application for an agricultural drone port for mobile remote monitoring.
- Demonstrated a waterproof, field-testable stationary sentinel for observing crops and the field environment with 3D AI-imaging, LoRaWAN, WiFi and solar power.
- The manuscript "Sensor-Based Quantification of Peanut Disease Defoliation Using an Unmanned Aircraft System and Multispectral Imagery" was published (https://apsjournals.apsnet.org/doi/10.1094/PDIS-05-23-0847-RE).
- Trained cotton disease AI-image detection models and automated training workflows for use on the stationary sentinel and other edge computers in the field.
- Multiple instance regression models using the MI-ClusterRegress algorithm were trained on point spectra obtained from cotton nitrogen trial plants.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024
FINAL REPORT

Project Title: 19_FLOWERING: Monitoring Flowering of Row Crops via High-Resolution Remote Sensing Platforms
Thrust(s): Thrust 3 – Agricultural Response Systems / Thrust 1 – Agricultural Sensor Systems /
Lead Faculty Investigator: Melba Crawford (Purdue)
Co-Investigator(s): David Cappelleri (Purdue)
Researcher(s): Liu, Quijano, Deb, Kim (PhD/Purdue), Jenness (Pilot/Undergrad/Purdue), Montgomery (Pilot/Undergrad/Purdue)

LOCATION ON 3-PLANE DIAGRAM: 2. Enabling Technologies (Robotics and Sensors) / 1. Fundamental Knowledge (Machine Learning)

TRL #: 7 **ARL #:** 7

OBJECTIVES & CENTER ALIGNMENT:

- Flowering is a critical stage in crop physiology, whose timing and extent are important to determining grain yield. Flowering data is included in many process-oriented crop simulation and prediction models, and field reference data are utilized to parameterize these models. Field based measurements, which require assessing the date that 50% of the plants are 50% flowered, are subjective and time consuming. Further, flowering occurs over short time periods and is ideally determined based on repeated daily evaluation. The objective of the initial years of this project was to develop capability for multi-temporal counting of tassels in plots with plant breeding and management practice trials, where flowering time was variable. Imagery was acquired by a Sony Alpha 7RIII RGB camera on a Freefly Alta-X UAV with an Applanix APX-15 for georeferencing. Images were processed to retain geometric fidelity of plant structures in close range orthorectified products and analyzed to detect and count tassels via a novel neural network architecture developed by the team (Liu et al, 2022)..
- The objectives of the project in its final year were to: a) investigate the capability of a small off-the-shelf platform which could fly much closer and view at non-nadir angles to the tassels to acquire more detailed information on the tassel during the flowering process, and b) evaluate the transfer learning capability of the original neural network architecture.
- The project aligns with the Center goals both in advancing sensing (Th 1) and agricultural response systems (Th 3).

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

- RGB images were collected during flowering in summer 2023 using a DJI Mavic Mini drone flown <1m above the canopy with a gimbal to acquire geo-tagged images at multiple viewing angles and compared to images acquired the same day by the original system flown at 20m. The non-nadir viewing angles at high resolution provided information on the flowering status of near range tassels, but inclusion of tassels from other rows in 2D images made discrimination more difficult and was abandoned.
- The deep learning model developed using 2021/2022 orthorectified imagery was successfully transferred to both the 2023 orthorectified and close-range images with

minimal tuning, demonstrating robustness to the quality and quantity of images to which it was applied. The algorithm reliably provides tassel counts through the flowering season, serving as a surrogate for evaluating true flowering.

- Tassels can also be counted in low cost near range photos using the pre-trained network for single date acquisitions where temporal alignment is not required.
- 201 citations are reported to date in Google Scholar for the tassel detection algorithm: Liu, K. Quijano, and M. Crawford, "YOLOv5-tassel: Detecting Tassels in RGB UAV Imagery with Improved YOLOv5 Based on Transfer Learning," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 15, 8085, 2022.

TESTBED & JOINT-OP ACTIVITY:

Imagery acquired from both platforms during the 2023 flowering period was collected over the Field 85 ACRE testbed where extensive field reference sampling was conducted for the Nitrogen Joint-Op experiment. Figures at the end of this report illustrate the results obtained for estimating flowering from both orthorectified RGB imagery and the near range high resolution photos.

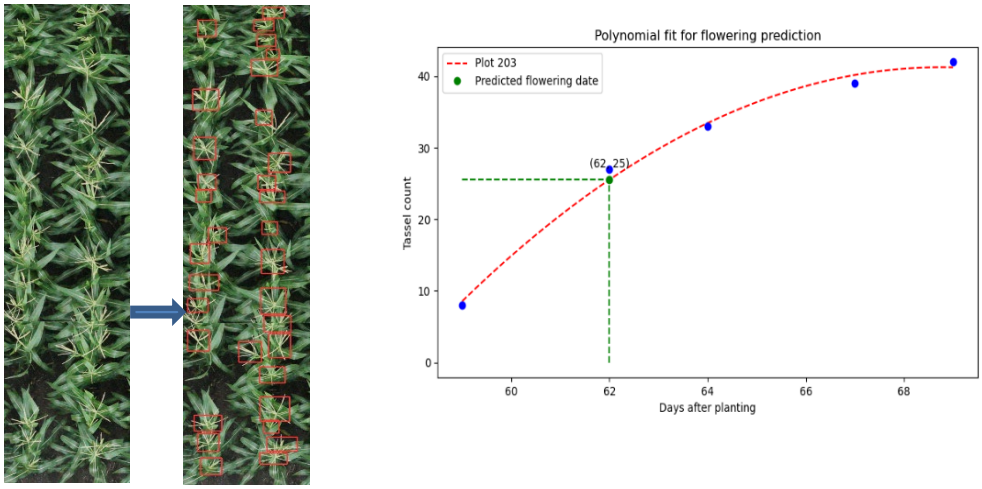


Figure 1. Example of 2 rows of orthorectified RGB imagery acquired at 20m, detected tassels, and multi-date predictions of tassel counts over the growing season



Image	Counting	GT
0460	21	21
0605	30	34
0787	23	23
0850	36	38

Figure 2. Tassel detection from non-orthorectified imagery acquired at 80 cm by DJI Mavic Mini on 7/31/2023

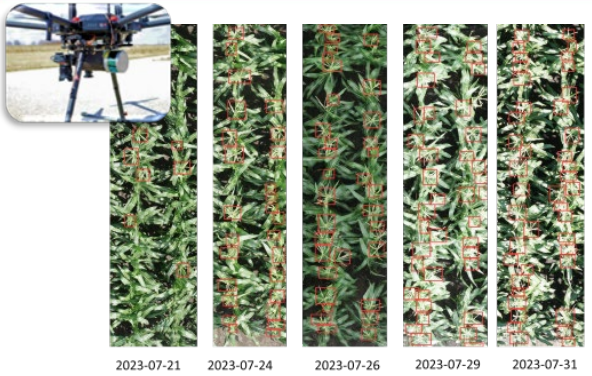
Project Title: 19_FLOWERING: Monitoring Flowering of Row Crops via High -Resolution Remote Sensing Platforms
Thrust(s): Thrust 3 / Thrust 1 **ARL / TRL:** 7 / 7
Faculty Investigators: Melba Crawford, David Cappelleri (Purdue)
Researcher(s): Liu, Quijano, Deb, Kim, Jenness, Montgomery (Purdue)

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PROJECT OVERVIEW

The project focuses on developing and demonstrating machine learning -based models for predicting flowering time in maize based on multi -temporal RGB imagery acquired from UAVs in a wide range of field environments. A second key objective is to demonstrate the capacity for near range sensing on low-cost UAV platforms, leveraging the generalization capability of the deep learning model with limited additional reference data. Transfer of the technology to agricultural researchers focused on plant breeding and management practice trials is an important ultimate goal of the project. Overall, this project is broadly aligned with the Center strategic plan relative to developing and delivering sensing technology (Thrust 1) in agricultural response systems (Thrust 3) for agricultural applications.

SUMMARY FIGURE



Plot: 203
Row: 2&3

Date	Counting	GT
2023/7/21	8	8
2023/7/24	27	27
2023/7/26	33	34
2023/7/29	39	41
2023/7/31	42	43

	Prediction	GT
Flowering date	2023-07-24	2023-07-24

RESEARCH APPROACH & BARRIERS

Approach in Year 4

- Investigate capability to monitor flowering via by small-scale low-cost platforms, leveraging the deep learning model developed for multi-temporal RGB orthomosaics derived from advanced integrated sensor platforms

Barriers:

- Barriers to success included weather related field conditions for data acquisition and the short period during which flowering occurs, coupled with the need for precision georeferencing on a low-cost platform. Deformation and occlusion of tassels during flowering period creates a challenging environment .

KEY ACCOMPLISHMENTS TO-DATE

- Achieved the key milestone of developing and implementing capability to estimate flowering time based on the surrogate measure of multi -temporal tassel counting.
- Demonstrated capability to develop high resolution orthomosaics derived from low altitude imagery, retaining the fidelity of complex objects.
- Demonstrated generalization of the deep learning -based detection model and few shot learning with limited reference data across sensing platforms.
- Disseminated results via publication of a highly cited paper in high impact factor journal
- Developed a high quality multi -temporal database of RGB orthomosaics and code base for advancing research in detection of complex objects across multiple domains

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: Project 20_CORN MASS N2: Corn Phenology, Biomass and Nitrogen Efficiency Prediction from Integrated Sensors
Thrust(s): Thrust 1 – Agricultural Sensor Systems / Thrust 3 – Agricultural Response Systems
Lead Faculty Investigator: Melba Crawford (Purdue)
Co-Investigator(s): Dan Quinn (Purdue)
Researcher(s): Aviles Toledo, Quijano, Morales (PhD/Purdue), Jenness (Pilot/Undergrad/Purdue)

LOCATION ON 3-PLANE DIAGRAM: Fundamental Knowledge/Science Engineering: Thrust 3, Sensor Fusion and Machine Learning

TRL #: 6 **ARL #:** 6

OBJECTIVES & CENTER ALIGNMENT:

The overarching objective of this project is to collect and utilize data from integrated sensors on UAV platforms, combined with ground reference sampling of corn phenology, biomass, and nitrogen (N) uptake, to develop end-of-season predictive models for development-stage specific biomass and N efficiency predictions. During the 2023 growing season, hyperspectral and LiDAR remote sensing (RS) data were acquired ~weekly by a UAV over the Purdue testbed, where N fertilizer was applied at 4 rates (0, 60, 120, and 180 lbs N/acre) to plots in a randomized complete plot design with a single variety at the beginning of the growing season. The long short-term (LSTM) stacked neural network model developed in previous years based on RS, environmental, and management practice data was extended to include a mid-season temporal attention mechanism to align with crop phenology, multi-modality architectures with late-stage fusion, and plant genetics. It was validated in both the Purdue testbed and in a plant breeding experiment in the Genomes-to-Fields program. Model generalization for yield prediction from multiple time periods in the growing season was successfully demonstrated via transfer learning, reducing requirements for reference data and training time for models.
The second key objective of the project is to contribute new integrating science in precision agriculture to support the IoT4Ag strategic plan and center-level goals for food and energy security. This interdisciplinary project has enhanced understanding of critical processes impacting nutrient stress development in maize production in field-scale experiments from physiology, modeling, and sensing perspectives. Innovations in sensing capability and modeling technology for earlier and more accurate nutrient stress detection will help advance precision agriculture aimed at enhancing nutrient efficiencies while providing critical data for developing data-driven predictive strategies. Contributions to both agricultural sensor system (Th 1) and models (Th 3) align with the ERC Center-level goals.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

Successful continuation of the prior years' nutrient management experiments under different conditions. The 2023 experimental design for the project was a testbed at the Purdue Agronomy Center for Research and Education (ACRE), that was similar to those of 2021/2022 with a single hybrid and 4 N fertilizer rates, but in a different field.

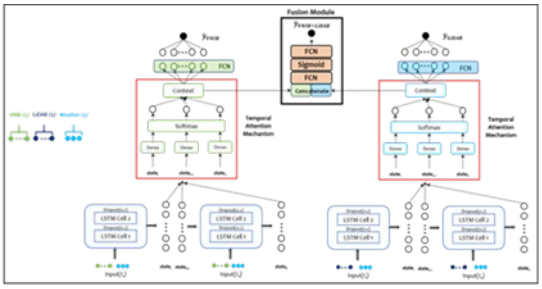
Extension of the LSTM neural network model and demonstration of the value of the temporal attention mechanism to increase explainability of the model in terms of crop phenology.

Demonstration of the impact of different combinations of multi-modality remote sensing data collections on end of year yield predictions.

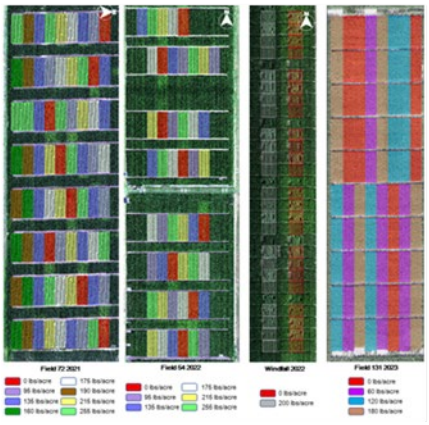
TESTBED & JOINT-OP ACTIVITY:

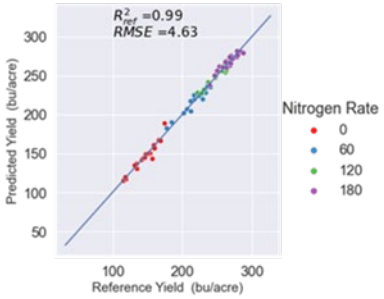
The experiment was conducted in the primary joint-op site. The extensive field reference and remote sensing data augment the rich data sets acquired over the full project period and will be made available to the community.





Multi-Modality LSTM





2023 Test Prediction with Few Shot Transfer Learning

Project Title: 20_CORN MASS N2: Corn Phenology, Biomass and Nitrogen Efficiency Prediction from Integrated Sensors

Thrust(s): Thrust 1 / Thrust 3 **ARL / TRL:** 6 / 6

Faculty Investigators: Melba Crawford, Dan Quinn, Tony Vyn (Purdue)

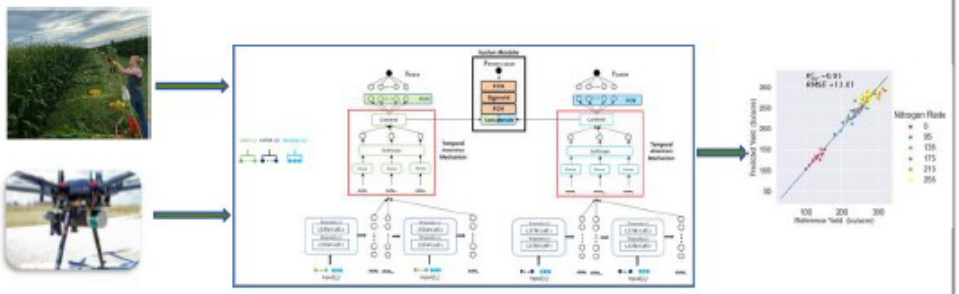
Researcher(s): Aviles Toledo, Quijano, Morales, Jenness (Purdue)

IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

PROJECT OVERVIEW

The project broadly aligns with the Center strategic plan relative to a) integration of field reference and multi-modality remotely sensed data for developing predictive models, b) development and utilization of the Purdue testbed, and c) engagement in the joint-op optimization of nitrogen (N) application in row crops. Predictive machine learning based models focusing on relationships between hyperspectral and LiDAR inputs at multiple growth stages and corn biomass and grain yield are being developed to investigate management practices and evaluate hybrids for plant breeding. N sufficiency (determined by N concentration and NNI (N nutrition index) is also being determined at multiple growth stages through field sampling to guide recommendations for in-season N mitigation and hybrid selection to improve N recovery efficiencies.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Approach in Year 4: The project is conducted each year, fully utilizing the Purdue maize testbed and contributes extensive data sets for potential integration with other IoT4Ag projects. Adoption of consistent protocols over data acquisitions in 3 vegetative-stage and 3 reproductive-stage flights timed to coincide with phenology, biomass, and tissue N concentrations collected from ground sampling from 2021-2023 (and currently in 2024) provide opportunities for testing the generalization of models over multiple geographic locations and annual weather patterns. Field trials involve multiple N rates to provide a range of outcomes at maturity for whole-plant biomass yield, grain yields, and final N efficiencies.

Barriers: Acquisition of cloud free remote sensing data during the relevant times of the growing season is a continued barrier. Adequate ground reference data to characterize sites is challenging; additional in-situ sensors were installed in 2023/24.

KEY ACCOMPLISHMENTS TO-DATE

- Achieved the key milestone of demonstrating capability of predicting of corn grain yield based on remote sensing, weather, and sampling data.
- In addition to demonstrating the LSTM predictive model with multiple nitrogen application rates and its generalization through few-shot transfer learning to other locations with different levels of nutrient applications, inclusion of a temporal attention mechanism and modification of the network to handle late fusion of multiple remote sensing modalities improved predictions and aligned with crop phenology.
- Engagement with external partners, including Corteva Agriscience and Pivot Bio in demonstration of the impact of nitrogen treatments, hybrids, and biological pre-treatment.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 21_AFLATOXIN: Assessing Aflatoxin Risk Points in Peanuts
Thrust(s): Thrust 1_Agricultural Sensors Systems / Thrust 3_Agricultural Response Systems
Lead Faculty Investigator: Brent Sumerlin (UF)
Co-Investigator(s): Cherie Kagan (Penn), Alina Zare (UF)
Researcher(s): Khouri Sader, Hamad, Pitts (PhD/UF), Mallavarapu (Postdoc/Penn), Vaughan, Guin, Inkeles (REU/UF)

LOCATION ON 3-PLANE DIAGRAM: 2. Fundamental Knowledge / 3. Enabling Technologies
TRL #: 4 **ARL #:** 2
Our current optimization efforts validated under in-vitro conditions within a controlled lab environment position our project at a TRL 4 and ARL 2. We are making significant strides in validating the MIP-based sensor specificity in adsorbing the target compound, a crucial step before integration into the Leafsense sensor developed by the Kagan lab at Penn and in-field applications. This progress is promising for future advancements in aflatoxin detection technologies. We have also made notable progress in predicting peanut maturity as a risk factor for aflatoxin and have identified another risk factor, enhancing our collective ability to predict or detect aflatoxin levels in peanuts.

OBJECTIVES & CENTER ALIGNMENT:
This project integrates chemistry with advanced technologies to develop a selective sensor for detecting aflatoxin, aiming to enhance crop quality through early contamination detection. The sensor uses molecularly imprinted polymer (MIP) networks which will be immobilized on optical metasurfaces being developed in the 1_LEAFSENSE project at the University of Pennsylvania. MIPs absorb aflatoxin, altering their refractive index and causing spectral shifts. We also use hyperspectral imaging (VNIR and SWIR) to detect aflatoxin contamination in peanut pods and seeds, providing a detailed view of contamination levels.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
In the third year of this project, we have made significant strides in the synthesis of MIPs targeted for aflatoxin detection. MIPs are specialized polymer matrices that possess cavities with sites complementary to the size, shape, and spatial arrangement of a molecular template introduced during polymerization. The Sumerlin lab has successfully fabricated a diverse library of MIPs using a template molecule, 5,7-dimethoxycoumarin (5,7-DMC), which mimics aflatoxin, and a selected series of mono- and multi-functional monomers. Post-polymerization, the template was removed, leaving behind vacant cavities ideal for rebinding experiments designed to evaluate the efficacy of the MIPs in comparison to non-imprinted polymer (NIP) control beads. Building on our previous work, we adjusted several parameters, as depicted in **Fig.1A**. These adjustments include variations in the nature of the monomers, the type of crosslinkers, the monomer-to-crosslinker ratios, and the polymerization times, which resulted in MIPs of differing morphologies and sizes. The efficacy of these MIPs is demonstrated in **Fig.1B**, where within the first 10 min of exposure, MIPs showcased an adsorption capacity (Q) that is up to three times that of the NIPs. Additionally, the specificity of our MIPs was assessed against a non-target (decoy) molecule, caffeine. As highlighted in **Fig.1C**, the polymer synthesized using methacrylic acid (MAA) demonstrated an imprinting factor (IF) of 1.37. This indicates successful imprinting, where the MIP binds the target molecule 37% more effectively than the NIP. In contrast, methyl methacrylate

(MMA) displayed a higher IF of 1.52. However, the IF for MMA with caffeine reached 1.78, suggesting that MMA is slightly less selective, tending to adsorb off-target molecules as well. Conversely, MAA exhibited a much lower IF of 0.3 for the off-target caffeine, confirming its high specificity for our target molecule. This analysis quantitatively established MAA as the preferred monomer for achieving high specificity in aflatoxin detection.

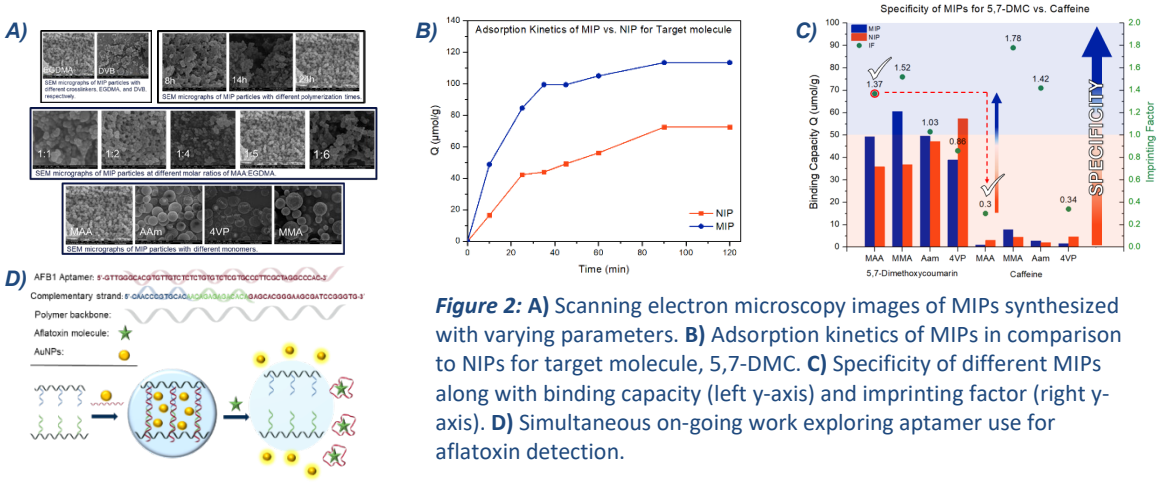


Figure 2: **A)** Scanning electron microscopy images of MIPs synthesized with varying parameters. **B)** Adsorption kinetics of MIPs in comparison to NIPs for target molecule, 5,7-DMC. **C)** Specificity of different MIPs along with binding capacity (left y-axis) and imprinting factor (right y-axis). **D)** Simultaneous on-going work exploring aptamer use for aflatoxin detection.

While our MIPs have demonstrated considerable success in selectivity and specificity, we are exploring in parallel the use of aptamers as the next generation for detection as aptamer-based sensors reduce false positives and exhibit enhanced sensitivities. Aptamers are short, single-stranded DNA or RNA molecules that bind with high specificity and affinity to specific target molecules. As illustrated in **Fig. 1D**, our research is exploring the potential of aptamers to enable a visual detection method that, when coupled with hyperspectral imaging (HSI), promises to significantly enhance real-time, field-based monitoring of aflatoxin. The visual signals produced by either MIPs or aptamers will allow for identification of regions of interest on the peanut seeds, which will then be used as ground-truth to train or validate a machine learning model. A pixel level classification model has already been trained and shows capabilities at correctly classifying abnormal vs normal peanut seeds. The effectiveness of this approach has been demonstrated by the Zare lab.

Abnormal seeds, identified by black mold, white mold, or yellow spores as shown in **Fig. 2**, are one of the risk factors that can lead to aflatoxin contamination. Hyperspectral images of both healthy and abnormal peanuts were collected, as depicted in **Fig. 3**. A machine-learning autoencoder, trained exclusively on spectra from healthy peanuts, has been employed to learn the characteristic spectrum of a healthy seed. Consequently, this autoencoder fails to reconstruct the spectra of abnormal peanuts, effectively classifying them as abnormal. Using a reconstruction error map, illustrates regions with high discrepancies in abnormal peanuts compared to the minimal errors in healthy ones.



Figure 2: Images of magnified peanut seeds that are abnormal

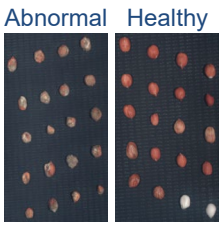


Figure 3: Hyperspectral images of abnormal peanuts and healthy peanuts

Project Title: 21_AFLATOXIN: Assessing Aflatoxin Risk Points in Peanuts

Thrust(s): Thrust 1 / Thrust 3

ARL / TRL: 2 / 4

Faculty Investigators: Brent Sumerlin, Zare (Florida), Cherie Kagan (Penn)

Researcher(s): Khouri Sader, Hamad, Pitts (Florida), Mallavarapu (Penn), Inkeles, Guin, Vaughan (REU)

IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

PROJECT OVERVIEW

This project aims to detect aflatoxin, a highly carcinogenic mycotoxin produced by *Aspergillus parasiticus*, which poses detrimental health risks to both animals and humans. To address this, we leverage innovative molecularly imprinted polymers (MIPs) as sensors to specifically and efficiently detect aflatoxin. By utilizing the optical metasurfaces synthesized by the 1_LEAFSENSE project, our MIPs can be immobilized onto these surfaces. When aflatoxin binds to the MIPs, it triggers a change in the refractive index of the polymer, resulting in a spectral shift in the array resonance. We are also developing machine learning algorithms to detect or predict the level of aflatoxin on peanuts using hyperspectral images of pods and seeds. In addition, hyperspectral images can be used to detect risk factors that may lead to aflatoxin such as peanut maturity and abnormal seeds (white mold, black mold, and yellow spores). This project aligns with IoT4Ag objectives by enabling sensors to collect and transmit critical data from contaminated sites to drones, facilitating timely actions and informed decision-making. This capability will enhance grower profitability, production, and crop quality by allowing for rapid detection and response to aflatoxin contamination.

SUMMARY FIGURE

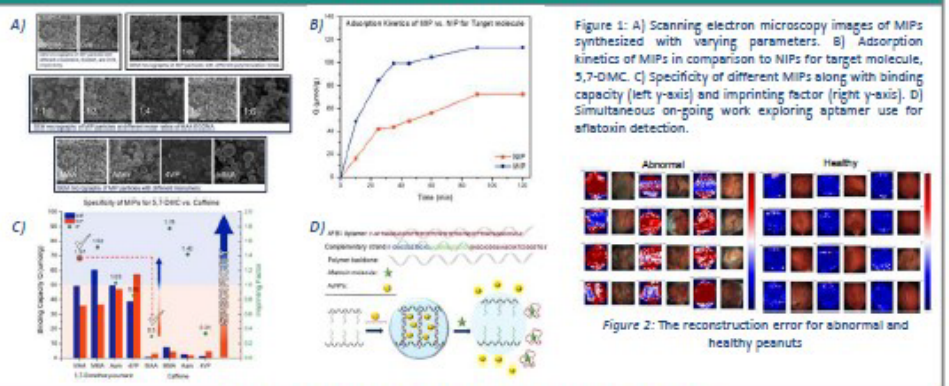


Figure 1: A) Scanning electron microscopy images of MIPs synthesized with varying parameters. B) Adsorption kinetics of MIPs in comparison to NIPs for target molecule, 5,7-DMC. C) Specificity of different MIPs along with binding capacity (left y-axis) and imprinting factor (right y-axis). D) Simultaneous on-going work exploring aptamer use for aflatoxin detection.

Figure 2: The reconstruction error for abnormal and healthy peanuts

RESEARCH APPROACH & BARRIERS

Our approach aims to measure aflatoxin presence and contamination levels in crops like peanuts. To achieve this, we are synthesizing a chemical sensor using multi- and mono-functional monomers that engage in supramolecular interactions with aflatoxin. This involves creating molecularly imprinted polymers (MIPs) with high specificity and selectivity for aflatoxin detection. In parallel, we are exploring aptamers, which are short single-stranded DNA or RNA molecules with high affinity for aflatoxin, to enhance detection capabilities and provide visual detection through color change, beneficial for hyperspectral imaging. A significant barrier is the toxic nature of aflatoxin, necessitating the use of a mimicking template, which may result in slight variations from actual detection performance. Both MIPs and aptamers face this challenge, and ongoing efforts aim to overcome these barriers to ensure accurate and reliable detection. Addressing these challenges is crucial for developing a robust method for detecting aflatoxin contamination, ultimately improving crop safety and quality. For algorithm development, an autoencoder was trained to reconstruct healthy peanut spectra to detect abnormal peanut seeds. The idea is that the spectra that the model did not observe during the training stage will have a high reconstruction error, hence detecting abnormal seeds.

KEY ACCOMPLISHMENTS TO-DATE

- Successfully fabricated MIPs with 5,7-DMC mimicking template molecule to detect aflatoxin.
- Varied different parameters of MIPs by exploring different monomers, crosslinkers, monomer-to-crosslinker ratios, and polymerization times to visualize impact on particle morphology and determine system efficiency, selectivity and specificity.
- Assessed and quantified the efficacy and specificity of MIP beads with non-imprinted polymer (NIP) control beads. MIP has binding capacity 3x of NIP. MAA was determined to be the best performing MIP, with an IF of 1.37 and the highest specificity.
- Initiated exploration of aptamers as a parallel effort to MIPs which provide a visual detection method through color change, improving detection potential.
- Detecting abnormal peanuts as a risk factor for aflatoxin with hyperspectral images.
- Developing an autoencoder and adjusting the number of layers and perceptrons such that the network has a small number of parameters.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 22_DATA FUSION: Multi-Resolution Raster Data Collection
Thrust(s): Thrust 3_Agricultural Response Systems / Thrust 1_Agricultural Sensor Systems
Lead Faculty Investigator: Erin Hestir (UC Merced)
Co-Investigator(s): Stefano Carpin, Reza Ehsani (UC Merced), Melba Crawford (Purdue), Alina Zare (UF)
Researcher(s): Nesslage, Adepoju (PhD/UC Merced), Dilmurat (Postdoc/UC Merced), Contreras, Malone (Undergrad/UC Merced)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems
TRL #: Raster Fusion: 4 **ARL #:** Drone CO2 Emissions: 4

OBJECTIVES & CENTER ALIGNMENT:

Improving image-image synthetic raster generation. Sensor fusion in IoT-enabled agricultural systems is critical for providing actionable multiscale data to farmers. The main challenge lies in integrating disparate datasets from various sensors and platforms, which span a wide range of spatiotemporal resolutions. Our project aims to advance the use of multi-source sensing as a data input for IoT4Ag applications. In the first two years, we focused on collecting a diverse array of remote sensing data, including multi-instance, multi-modal, multi-platform, and multi-resolution datasets. By the third year, we successfully implemented various fusion approaches, with a notable achievement in integrating UAV-based data with satellite data, allowing us to estimate vegetation fractional cover with high spatial and temporal resolution.

Building on this success, our primary focus in the fourth year was on detecting water stress in plants. We extended our work to include different data sources and cropping systems, specifically targeting row crops. Additionally, we incorporated in-situ point-based measurements to improve predictive capabilities across a broader range of diagnostic variables. This approach will enable us to simulate high-resolution raster data products of key variables, which improves precision mapping for the application of irrigation, and in the future fertilizers, and pesticides. This, in turn, reduces labor, travel, and the overheads associated with high-frequency UAV acquisitions. Utilizing free, open-access satellite data has also lowered costs and democratized mapping goals, making the technology accessible to a broader group of end users and supporting ERC's outreach and educational objectives. Through improved precision mapping and reduced operational overheads, we are enabling more efficient and environmentally friendly agricultural practices.

Assessing the effects of drone operations on center Sustainability and CO_2 emissions. In line with ERC's goal of promoting a sustainable food production system, we undertook a comprehensive assessment of the environmental impacts of drone operations. Our objective was to finalize the life cycle assessment of various UAV-based remote sensing modalities, including RGB, hyperspectral, and multispectral technologies. We aimed to determine the greatest emission sensitivities related to the manufacture of components and hardware, as well as operational factors such as ground transport to sites and data storage.

By analyzing the entire University of California drone operations, we sought to quantify the global warming impact of large-scale drone use. This study provided a transparent method to assess the environmental footprint of drone operations, offering valuable insights for ERC's

stakeholders, partners, and the public. Our findings serve as a model for understanding and mitigating the CO_2 emissions associated with UAV technology, while still meeting production needs for IoT4Ag applications. Life cycle assessments provide critical transparency, allowing us to quantify the global warming impacts of new technology deployment. This work enhances our understanding of the environmental impacts of drone operations and establishes a model for communicating and reducing CO_2 emissions in IoT4Ag technology applications.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

Improving image-image synthetic raster generation.

- Incorporated in situ data with raster data to create spatial predictions of soil fungal community biodiversity based on environmental DNA collected from soil samples, airborne lidar data, and PlanetScope multispectral satellite data using generalized dissimilarity modeling, with 35% of the variance explained by geographic and environmental variables.
- Developed new collaboration with UC ANR and Sorghum Board to extend work to row crops, taking advantage of a unique experimental design for sorghum variety breeding that includes deliberate and well documented irrigation reduction treatments across a randomized block design across three different sites in California spanning a large latitudinal gradient with different climate and soil types.
- Showed that UAV-based multispectral data and PlanetScope satellite data can detect water stress in sorghum fields using both spectral indexes (e.g., NDVI) and machine-learning approaches.
  - Demonstrated that spectral index values were significantly different across irrigation treatments (100%, 50% and 30%).
  - Demonstrated that irrigation treatments were differentiable with high accuracy using satellite data (multispectral PlanetScope, daily revisit, 3m pixel resolution).
  - Used these data to identify sorghum breed that may be more resilient to water stress.

Assessing the effects of drone operations on center Sustainability and CO_2 emissions.

- Used LCA to show that Travel to and from field sites is the dominant driver of CO_2-eq emissions related to the use of UAV-based remote sensing systems in the ag and environmental sectors. Among the remaining 2.4%-3% of CO_2-eq emissions, materials production, transport of the UAV to the customer, manufacturing, and battery charging has the greatest impacts.
- Implications for operators and new technology: changes in behaviors can mitigate CO_2 emissions these impacts, specifically reducing the number of trips. Improvements are needed for advancing battery efficiency and extending flight duration and area.
- Implications for industry: In the UAV industry, we see interest in providing UAV-based remote sensing as a service to the agricultural sector and competing interests in providing autonomous drone fleet services that stay within fields. Our findings suggest that the most sustainable UAV-based services will be those located as close as possible to the farm, field, or area of interest.

TESTBED & JOINT-OP ACTIVITY:

Testbed: Utilized PlanetScope imagery to detect changes in water stress of pistachios at the pistachio Test Bed over the summer months (June, July, and August of 2022).
Joint-Op: Advanced the utility of UAV/Satellite data for water stress detection in Merced orchard test bed and in new row-crop demonstration case.

Project Title: 22_DATA FUSION: Multi-Resolution Raster Data Collection

Thrust(s): Thrust 3 / Thrust 1 **ARL / TRL:** 4-5 / 3-4

Faculty Investigators: Erin Hestir, Reza Ehsani, Stefano Carpin (Merced), Melba Crawford (Purdue), Alina Zare (Florida)

Researcher(s): Nesslage, Adepoju, Dilmurat, Contreras, Malone (Merced)

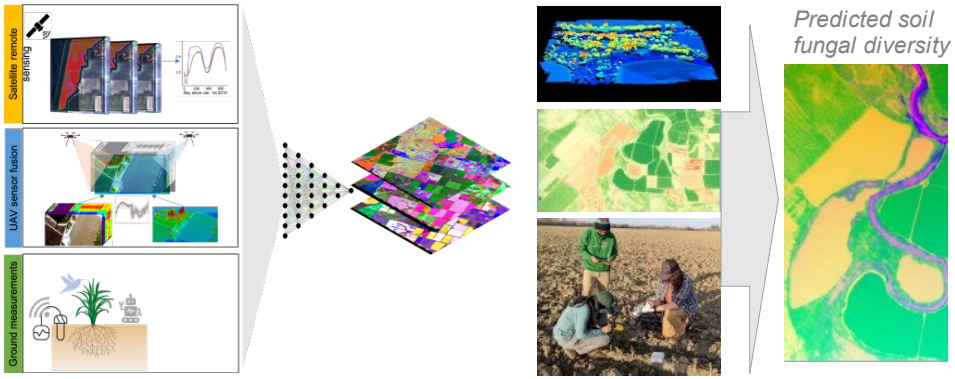
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PROJECT OVERVIEW

Grower Insights	In-Situ Sensors	UAV	Airborne	Spaceborne
✓ Serves as a check on IoT enabled farming systems	✓ High precision data at the individual/plot/field level	✓ High spatiotemporal resolution data on demand	✓ High spatial and spectral resolution	✓ Frequent, predictable revisit times
✗ Can be difficult to incorporate into datasets	✗ Point or small area coverage	✗ Small area coverage	✗ Costly, infrequent revisits	✗ Low to moderate spatial resolutions

Sensor fusion in IoT-enabled agricultural systems is critical for providing actionable multiscale data to farmers. Through improved precision mapping and reduced operational overheads, we are enabling more efficient and environmentally friendly agricultural practices.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Improving synthetic raster generation

Generalized dissimilarity modeling using satellite and aircraft remote sensing and in situ soil samples (environmental DNA).

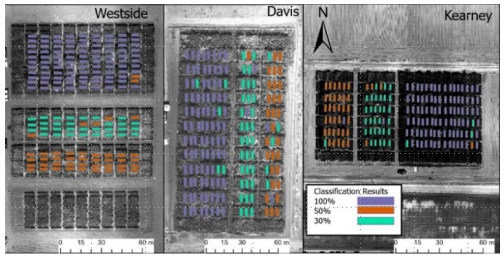
Advancing Joint -Ops Water: New sorghum collaboration provides unique opportunity to develop water stress detection with known treatments across many genotypes.

Machine learning and spectral indexes used for multispectral UAV and satellite data, deployed to pistachio test bed and new row crop (sorghum) experiment.

Global warming impact of drone operations

Life Cycle Assessment to quantify cradle-to-grave CO2 emissions for drone manufacture and operations, scaled to the entire UC system.

KEY ACCOMPLISHMENTS TO-DATE



ML model results to detect irrigation reductions in sorghum fields across California using satellite data.

Demonstrated capability to predict soil fungal diversity using multisource remote sensing and in situ data

Showed UAV-based multispectral data and PlanetScope satellite data can detect water stress in sorghum fields

Made recommendations for more sustainable drone tech development and operations in Ag

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 24_BIOPHYSICS: Biophysical Model Enablement
Thrust(s): Thrust 3_Agricultural Response Systems / Thrust 1_Agricultural Sensors Systems / Thrust 2 – Communication and Energy Systems
Lead Faculty Investigator: Dennis Buckmaster (Purdue)
Co-Investigator(s): Dan Quinn, Jim Krogmeier (Purdue)
Researcher(s): Pathak, Balmos (PhD/Purdue), Olivia (MS/Purdue)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems
TRL #: 5 **ARL #:** 3

OBJECTIVES & CENTER ALIGNMENT:
Most of the existing decision support tools for nitrogen fertilizer recommendation focus on yield response (for example: yield goal method, maximum return to nitrogen) but fail to embrace biocomplexity and the spatial variability of soil and weather. Crop growth models or biophysical models, such as APSIM, DSSAT, could address those issues but requires numerous inputs and parameters, which reduce their adoption by stakeholders (extension educators, farmers, or agronomists). Furthermore, biophysical models fail to help in making in-season farm management decisions. Our approach seeks to manage the complexity by considering the effect of past and present weather and soil states, and the impact of the N application on the environment in based on simulated projections based on weather possibilities through APSIM and creating the easy-to-use user-interface and shielding the user from the complexity of tool. The primary objective of this project is to create a user-friendly decision-support tool with an aim to increase its adoption and help make stakeholders informed and adaptive farm management decisions within the season to achieve economic, environmental, and social sustainability. We will achieve this by (i) comparing APSIM simulations with field experiments by varying N-rates and timings (ii) developing a DST (OPTICORN), based on APSIM, to recommend N-fertilizer application rate and timing by integrating management, soil, and weather information, (iii) conducting user testing workshops for farmers, extension educators, researchers for using OPTICORN, a DST to improve usability and effectiveness of the tool.
The overall vision and mission of the IoT4Ag plans and center-level goals are to increase crop production by reducing the use of water and nutrients and achieve environmental and economic sustainability. The project perfectly aligns with the THRUST 3 aim of response systems which integrate data sets, data streams, and biophysical models. While the first "topic" is nitrogen management, similar approaches can be used for water management and perhaps eventually farm activity planning (sequence and timing of events on fields).

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
The key accomplishments were:

1. We organized the user-interface design workshop with stakeholders and subject matter experts, involving researchers and extension educators, to map the input features considered while making nitrogen fertilizer application decision, the corresponding outputs of interest. Furthermore, worked with them to create the easy-to-use interface by following the principles of software engineering, which are briefly shown in Figure 1. By utilizing

the recommendations from the farmers and brief discussion within the panel, the final user-interface is created using Shiny R.

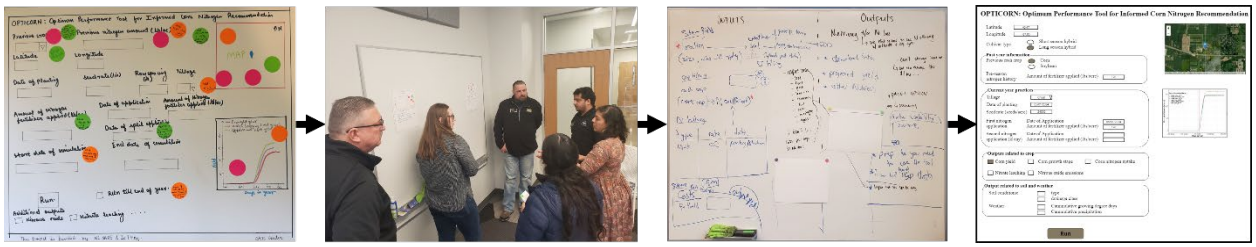


Figure 3 : Flowchart of overall approach illustrating different stages and processes of user-interface designing, starting with gallery walk and voting method, to user-interface creation, and followed by final agreed version

2. The back-end model in OPTICORN works on APSIM, which uses soil, weather, and management practices to simulate the corn production and provide desired outputs. We utilized location data to fetch soil, weather, and historical field records and the minimal management data needs to be entered by user.
3. A portion of this work was presented in ASABE 2023 (Presentation Excellence Award), ASA/CSSA/SSSA meeting (as an invited speaker) in November 2023 and ICPA July 2024.

TESTBED & JOINT-OP ACTIVITY:

We will be utilizing the data from Joint Op 1 test bed along with the data coming from Dr. Quinn's field experiments trials to fine-tune (calibrate) the model and test its performance.

Project Title: 24_BIOPHYSICS: Biophysical Model Enablement

Thrust(s): Thrust 3 / Thrust 1

ARL/TRL: 3 / 5

Faculty Investigators: Dennis Buckmaster, Jim Krogmeier, Dan Quinn (Purdue)

Researcher(s): Pathak, Balmos, Olivia (Purdue)

IoT4Ag
The Internet of Things for Precision Agriculture
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PROJECT OVERVIEW

Project Goals: The overall vision and mission of the IoT4Ag plans and center -level goals are to increase crop production by reducing the use of water and nutrients and achieve environmental and economic sustainability. The project perfectly aligns with the THRUST 3 aim of response systems which integrate data sets, data streams, and biophysical models. The objective of this research were (i) comparing APSIM simulations with field experiments by varying N -rates and timings (ii) developing a DST (OPTICORN), based on APSIM, to recommend N-fertilizer application rate and timing by integrating management, soil, and weather information, (iii) conducting user testing workshops for farmers, extension educators, researchers for using OPTICORN-OS, a DST to improve usability and effectiveness of the tool.

SUMMARY FIGURE

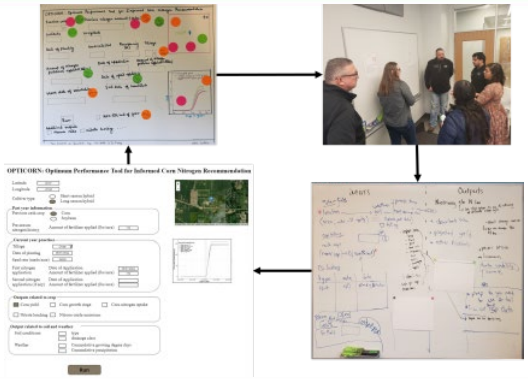


Figure 1: Flowchart of overall approach illustrating different stages and processes of user-interface designing, starting with gallery walk and voting method, to user-interface creation, and followed by final agreed version

RESEARCH APPROACH & BARRIERS

Approach: Conducted a user-interface design workshop with extension educators and researchers to map the features (inputs) and desired outputs, and corresponding user-interface design for OPITCORN. As shown in Fig 1., OPTICORN utilizes location data to fetch agrometeorological, soil, and historical yield data and management practices to simulate the corn production and predict the effect of nitrogen treatment at different growing stages of corn. We are also utilizing test-bed data along with some other field experiment data from Dr. Quinn to test the model performance.

Barriers: Extrapolating the model at regional level (reduces confidence in outputs due to involvement of variation in crop, weather, soil, and management parameters). A barrier to adoption is trusting a model to be “good enough for the decision at hand”.

KEY ACCOMPLISHMENTS TO-DATE

Accomplishments: Conducted the user-interface design workshop and developed the user-friendly front-end. Created the back-end algorithm, which utilizes the weather, soil, and management data to simulate corn production. A portion of this work was presented in ACS and ICPA conference, which highlights that the yield, nitrate leaching, and nitrous oxide emissions is sensitive to each of the stated parameters and hence need adaptive farm management strategies.

Future work: Integrate the front-end with back-end and test the performance of tool. Frame questions and conduct another workshop with extension educators and obtain feedback on the working of the tool. Long term: integrate NATS messages of crop and soil status to re-run the model on a schedule based on streamed data.

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 27_DATA INTEGRATION: Data Interoperability and Integration
Thrust(s): Thrust 3_Agricultural Response Systems / Thrust 2 – Communication and Energy Systems
Lead Faculty Investigator: Dennis Buckmaster (Purdue)
Co-Investigator(s): James Krogmeier (Purdue)
Researcher(s): Basir, Castiblanco, Balmos (PhD/Purdue)

LOCATION ON 3-PLANE DIAGRAM: Enabling Technologies
TRL #: 4 **ARL #:** 2

OBJECTIVES & CENTER ALIGNMENT:
The project was designed to integrate data from disparate sources, and to develop a comprehensive framework that collects information from farm machinery, sensors, public weather databases, soil surveys, and contextual metadata. By consolidating these varied data streams, the aim was to provide a robust foundation for advanced agricultural analytics and decision-making facilitating interoperability.

The project aimed to facilitate interoperability by implementing a system that converts diverse data formats into atomic messages, ensuring seamless compatibility across different data entities. This approach addresses the challenges posed by variability in spatial and temporal resolution, developing methods to align data with varying granularities.

The IoT centric integration of data aligns with the objectives of IoT4Ag, creating and translating Internet of Thing (IoT) technologies for precision agriculture. This project facilitates data integration in IoT environment providing scope of data interoperability between different data sources and users.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

Vehicle position is tracked real-time and data stream was integrated in Avena ecosystem
The Avena ecosystem, developed by Balmos et al. (2022), was utilized for real-time position streaming of agricultural vehicles. As a practical application of Avena, a data pipeline was established to facilitate the exchange of GPS sensor data mounted on these vehicles. The data was published as atomic event messages and handled in a publish-subscribe mode. The Context Abstraction Service (CAS), an authenticated subscriber, was designed to receive these messages, which were initially published by a Hardware Abstraction Service (HAS). In Avena, abstraction services function as algorithms that convert sensor data into atomic event messages (HAS) and subsequently translate the published data into a format that is usable by subscribers (CAS).

Public repository data was integrated to Avena ecosystem in response to location and time
Data from public repositories (soil survey data and weather data) was fetched and published in Avena ecosystem and integrated with other data sources. To handle the system of data fetching and publishing, an abstraction service was introduced as Public Data Abstraction Service (PDAS) which works as a content abstraction service in the style of a HAS. On demand, the PDAS fetches

the data from online public repositories and breaks the data into singular event messages for publishing in Avena ecosystem. For instance, soil survey data was extracted from SSURGO On-Demand Repository using an XML purser and the data was published as single event messages that contains only requested data. Similarly, the PDAS for public weather data gets the data from *OpenweatherMap* and publishes the data on demand.

The PDAS does not interpret or manipulate the data but translates it into atomic event messages. PDAS data was fetched on-request with a location and time from the IsoBlue on vehicles. The system was tested on a simulated IsoBlue with real time spatial -temporal data.

Schema was developed to integrate contextual metadata of agricultural operations.
A schema was developed, and work is ongoing to deploy the Avena data pipeline for exchanging operational metadata. A semi-automated metadata collection app, Meta Ag, created by Basir et al. (2023), captures the spatial and temporal data of agricultural operations, while a rule-driven chatbot gathers detailed operation information with a user-centric design. The NATS messaging system, used for event-driven architecture, transmits the collected metadata within the Avena environment, enabling contextualization of data generated by sensors, vehicles, and other sources in the Avena ecosystem. Integrating this metadata will create data synergy, enhancing data interoperability.

TESTBED & JOINT-OP ACTIVITY:
We now have the capacity to layer weather, soil, and machine activity data for any testbed (Purdue ACRE, FL fields and orchards, CA orchards) in a NATS-enabled messaging format. Machine activity requires CAN GPS or LoRaWAN compatible trackers (such as Oyster), but soil only requires a lat/long location; weather queries require lat/long location and a time period.

Project Title: 27_DATA INTEGRATION: Data Interoperability and Integration

Thrust(s): Thrust 3 / Thrust 2

ARL / TRL: 2 / 4

Faculty Investigators: Dennis Buckmaster, Jim Krogmeier (Purdue)

Researcher(s): Basir, Castiblanco, Balmos (Purdue)

IoT4Ag
The Internet of Things for Precision Agriculture
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PROJECT OVERVIEW

The project was designed to integrate data from disparate sources and develop a comprehensive framework that collects information from farm machinery, sensors, public weather databases, soil surveys, and contextual metadata. Integrating these varied data streams, the aim was to provide a robust foundation for advanced agricultural analytics and decision-making.

To facilitate interoperability, the project implemented a system that converts diverse data formats into atomic messages, ensuring seamless compatibility across different data entities. This approach addresses challenges posed by variability in spatial and temporal resolution, developing methods to align data with varying granularities.

The IoT-centric integration of data aligns with the objectives of IoT4Ag, creating and translating IoT technologies for precision agriculture. This project enables data integration in an IoT environment, providing data interoperability between different sources and users.

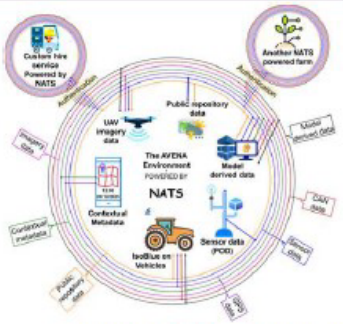
SUMMARY FIGURE



Approach of operational metadata integration in Avena



General approach of public data integration in Avena ecosystem



Integrating Data sources in avena framework

RESEARCH APPROACH & BARRIERS

Approach: The work was carried out using Avena framework to reframe time and location dependent data as atomic messages. The abstraction services for data publishing and receiving were tested using virtual IsoBlue and data from vehicle were recorded from the GPS sensors on vehicles at ACRE. The work will facilitate the work in testbeds by aligning data layers more readily.

Barriers: Streaming of data has been demonstrated. A barrier is the storage and longer-term retrieval of such data. Linking models to NATS and NATS to models requires further work and integration of imagery data as bit-sized messages may not be optimal.

KEY ACCOMPLISHMENTS TO-DATE

- ✓ Public repository data was integrated to Avena ecosystem in response to location and time
- ✓ Vehicle position is tracked real-time and data stream was integrated in Avena ecosystem
- ✓ Schema was developed to integrate contextual metadata of agricultural operations.
- ✓ *Two conference papers have been submitted:*

ASABE Aim-2024 (July 28-31, 2024, Anaheim, CA): Elevating Sensor Intelligence: Merging Agricultural IoT Streams with Public Data Repositories

ICPA 2024 (July 21-23, 2024, Manhattan, Kansas): Avena: An Event-Driven Software Framework for Informed Decisions and Actions in Cropping Systems

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 28_TECH ADOPTION: Barriers to Adopting IoT4Ag Technology: Mixed Methods Research Study
Thrust(s): Thrust 3 – Agricultural Response System / Thrust 1_Agricultural Sensor Systems
Lead Faculty Investigator: Lisa Yeo (Merced)
Co-Investigator(s): Catherine Keske (Merced), Kathryn Stofer (UF), Sebastian Galindo (UF)
Researcher(s): Sun (PhD/Merced), Nickerson (PhD/UF), Naranjo (MS/UF), Hoang (Undergrad/Merced)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems (Integration / Stakeholders)
TRL #: N/A **ARL #:** N/A

OBJECTIVES & CENTER ALIGNMENT:
The primary goal of this project is to identify how to reduce barriers to technology adoption, "*advancing technology to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment.*" Inherent in this is deliberate engagement of interest holders from marginalized populations in agricultural production, contributing to the long-term goal of including multidisciplinary, convergence research focus for broadening research impact and producing technology that is inclusive of farmer experiences.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
One of our primary goals for year four was to develop potential mitigation strategies to address barriers to adoption. Through comprehensive interview analysis with a small group of tree-nut farmers in California, we identified several pathways forward. Our key findings highlighted the critical role of community engagement, which fosters trust by actively involving end-users in the development process. We also emphasized the need for solutions that align with economic viability, enhancing their practical relevance and likelihood of adoption. Demonstrating the effectiveness of these solutions further strengthens grower trust, a cornerstone of the overall adoption strategy.

Building on Year 3 data, this year we concentrated on analyzing and publishing the existing interview data and conducting further listening and literature review on precision agriculture. This strategic decision led to notable outcomes, including the acceptance of a peer-reviewed conference presentation and the journal submission of a full paper currently under review. As illustrated in Figure 1, grower trust is shaped by both context and peers, then adjusted through experience. Notably, concerns about data management (e.g., governance, quality, privacy, security) are secondary to more immediate concerns such as profitability. These insights contribute to ongoing debates in digital agriculture, particularly around the balance of benefits and challenges posed by technological advancements in the field.

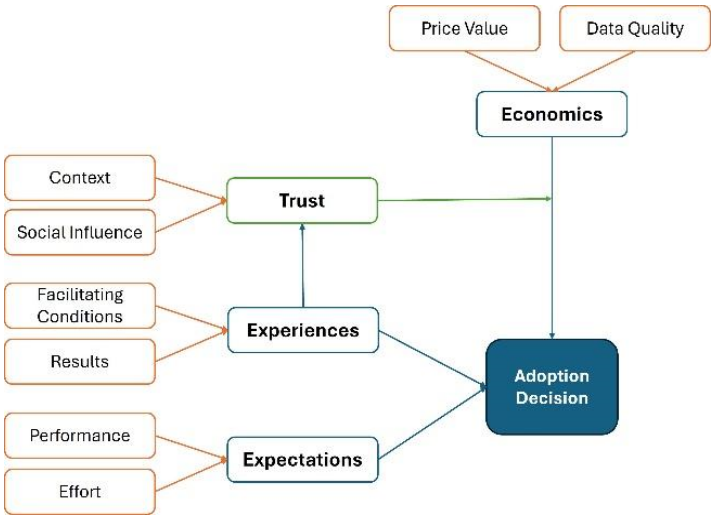


Figure 4. Conceptual Model of AgTech Adoption Decision.

We aimed to understand how data generate value for decision-making. The interviews provided initial insights into this area, revealing some patterns and tendencies. To build on this foundation, we conducted a deeper literature review, which illuminated how others have studied and identified valuable findings in this domain. This combination of empirical data and literature review has enriched our understanding and will guide future research directions.



Figure 5. Interest holders engaged in 1-1 discussions with Naranjo.

In Year 4 we engaged the agricultural community, including both end-users in agriculture and internal personnel, to build toward the co-development of technology (See Figures 2 and 3). A literature review, discussions, and listening sessions created a comprehensive map showing interested communities and their needs, resulting in a student poster presentation at the tri-center ERC conference in July 2024.

We also submitted a peer-reviewed publication on engaging with farmers for researchers who want to co-develop technology to minimize barriers to adoption and hired a communication technician in collaboration with Project 34 to produce event materials, kits, and guides to help internal center personnel with engagement with farmer and broader communities.

A final objective was the development of technology readiness scales for IoT4Ag. With center leadership, in 2023 Galindo led a center-wide session at the annual retreat on setting technology readiness levels, which built to a collaborative effort to define an IoT4Ag technology readiness level scale and create a new, end-user oriented adoption readiness level scale delivered in 2024.

The almond farmer interviews were the first phase of a mixed methods research project. Using factors identified in these interviews we are designing a choice experiment to assess farmer decision making.

Two significant milestones were accomplished for this project: a) adoption barriers and potential mitigations were identified, with a manuscript currently under review, and b) an end-user oriented adoption readiness level was developed. Looking ahead to next year, the focus will shift to addressing technology transfer challenges through economic analysis and determining willingness to pay for new technology based on device features and data ownership policies. Additionally, we plan to convene users and developers to collaboratively identify and implement strategies for optimal technology development and diffusion.

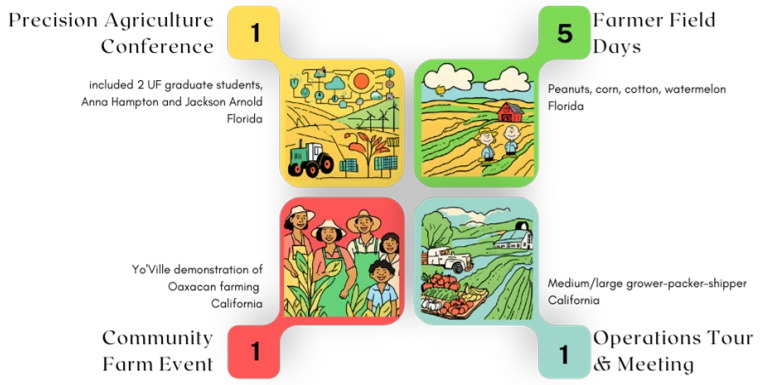


Figure 6. Nickerson, Naranjo, and Stofer created a calendar for events to attend annually to meet with agriculture communities and attended eight events in Florida and California this project year, as indicated.

TESTBED & JOINT-OP ACTIVITY: Project 28 supports all testbeds and Joint Ops.

Project Title: 28_TECH ADOPTION: Barriers to Adopting IoT4Ag Technology: Mixed Methods Research Study

Thrust(s): Thrust 3 / Thrust 1 **ARL / TRL:** N/A

Faculty Investigators: Lisa Yeo, Catherine Keske (Merced), Kathryn Stofer, Sebastian Galindo (Florida)

Researcher(s): Sun, Nickerson, Naranjo, Hoang (Merced)

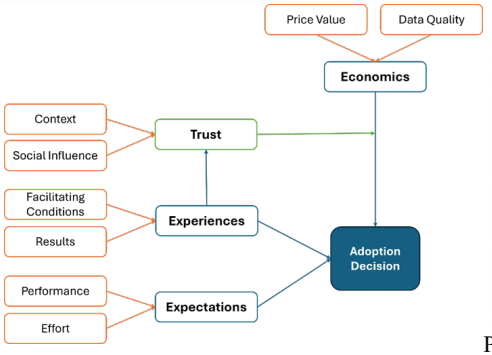
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PROJECT OVERVIEW

The primary goal of this project is to reduce barriers to technology adoption in agriculture, to *advance technology that increases crop production while minimizing energy and water use and reducing environmental impact* . An equally important goal is to engage stakeholders from underserved communities, fostering multidisciplinary, convergent research that broadens impact and ensures technology inclusivity for farmers.

Our stakeholder engagement plan aims to make tech adoption more strategic, synergistic, sustainable, and aligned. By understanding our connections and interactions within and beyond the agriculture system, we can address diverse values, interests, and positions. This diversity creates challenges in reaching a consensus on tech adoption, despite known problems and solutions.

SUMMARY FIGURE



Conceptual model of agtech adoption decision

Actions	Flow of information to and from stakeholders	Outcomes
Inform and collect information	→	Deliver information to stakeholders and initiate relationship building
Consult and involve	→ ←	Improve a service through stakeholder evaluation
Exchange and co-produce	↔	Bring stakeholders into the research process and co-produce intended outputs through knowledge exchange

Potential outcomes and corresponding actions for participatory projects. (fr. Furman et at., 2019)

RESEARCH APPROACH & BARRIERS

Approach/Methodology

- Comprehensive interview analysis with tree -nut growers in California to identify pathways for technology adoption.
- Gather values, interests, and positions from primary & secondary sources (e.g. interviews, educational videos, newspapers, farmer blogs, community gatherings, & government reports).
- Complex system theory will be used to develop Horizontal and Vertical alignments to create a common vision to tech adoption.

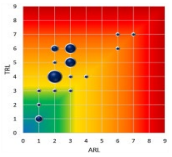
Barriers

- Building trust with stakeholders takes time.
- Interviews must take place outside of busy Spring and Summer growing seasons.
- Labor constraints hindered collecting additional interviews in California.

KEY ACCOMPLISHMENTS TO-DATE

Research Insights

- Trust and perceived benefits vs. profitability are major barriers to tech adoption.
- Despite data management issues (quality, storage, privacy, useability, etc.), high levels of trust identified regarding data security.



Stakeholder Engagement

- Developed End -User Adoption Readiness Scale.
- Engaged diverse groups (farmers, consultants, sales reps, non -profits, local government, extension agents) to understand their views on PA.
- Built trust & identified key influencers & communication channels.

Manuscripts Submitted

- From profitability to trust: Factors shaping digital agriculture adoption.
- Promising Practices for Farmer Engagement for Technology Development

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 29_ROBOT COMM: Deployment of Autonomous Ground Robots to Facilitate Communication.
Thrust(s): Thrust 2_Communication and Energy Systems / Thrust 3 – Agricultural Response System
Lead Faculty Investigator: Alejandro Ribeiro (Penn).
Co-Investigator(s): Dave Cappelleri (Purdue), Stefano Carpin (UC Merced), Vijay Kumar (Penn)
Researcher(s): Agarwal (Postdoc/Penn), Vatnsdal, Owerko (PhD/Penn)

LOCATION ON 3-PLANE DIAGRAM: 2. Enabling technology / 3. Systems
TRL #: 4 **ARL #:** 3

OBJECTIVES & CENTER ALIGNMENT:
Navigating a swarm of robots through an environment to achieve a common collaborative goal is a challenging problem, especially when the sensing and communication capabilities of the robots are limited. These problems require high-fidelity algorithms comprising three key modules: perception, action, and communication, which are executed in a feedback loop, i.e., the Perception-Action-Communication (PAC) loop. A decentralized system is of significant practical importance as it does not suffer from a severe communication bottleneck and is scalable to large robot swarms and large environments.

Such scenarios are particularly relevant in agriculture industries where robot swarms can be deployed for routine tasks such as inspection for weeds and pests, estimating harvest yield, and analyzing health of crops. Use of robot swarms for such applications provide (i) ability to continuously adapt to changing environment (ii) rapid coverage of large fields, and (iii) repeatability in information acquisition for reliable longitudinal data comparison and analysis.

However, designing a navigation algorithm for a decentralized system is challenging as the robots perform perception and action independently, while the communication module is the only component that can facilitate collaboration between the robots. Under limited communication capabilities, the robots must decide what information to communicate to their neighbors and how to use the communicated information to take appropriate actions. Graph neural networks (GNNs) have been shown to be particularly suitable for this task as they can operate on a communication graph---the graph imposed by the communication topology of the robots---and can learn to aggregate information from neighboring robots to make decisions. Furthermore, GNNs exhibit several desirable properties for decentralized systems: (i) transferability to new graph topologies not seen in the training set, (ii) scalability to large teams of robots, and (iii) stability to graph deformations.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:
We develop a learnable PAC architecture, as shown in Figure 1, composed of a convolution neural network (CNN) to process localized robot perceptions, a GNN to communicate information between robots and aggregate information from neighbors, and a shallow multilayer perceptron (MLP) to predict actions, thereby unifying the PAC loop for the coverage control problem.

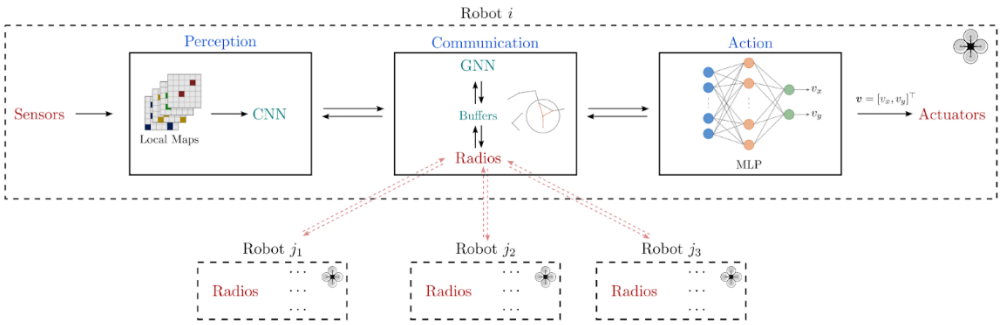


Figure 1: The proposed architecture for decentralized coverage control. The robot observations are processed by a CNN to extract features, which are then communicated to the neighboring robots using a GNN. The GNN predicts the control actions for the robots.

TESTBED & JOINT-OP ACTIVITY:

We evaluate the performance of our learning-based models on realistic environments. The models are trained on 1024 m x 1024 m environments with 32 robots and features. The sensor size is 64 m, and the communication radius is set to 128 m. The evaluation is performed on environments of size up to 2048 m x 2048 m. Our experiments establish the following:

(a) The model outperforms the baseline centralized and decentralized CVT algorithms. It learns to share relevant abstract information, which is generally challenging to design for decentralized algorithms.

(b) The model generalizes to environments with varying numbers of robots and features, especially when they are larger than the training distribution.

(c) The model transfers well to larger environments with a larger number of robots while keeping the ratio of robots to environment size the same.

(d) Even though the model is trained on synthetic datasets with randomly generated features, it performs well on real-world datasets without further training.

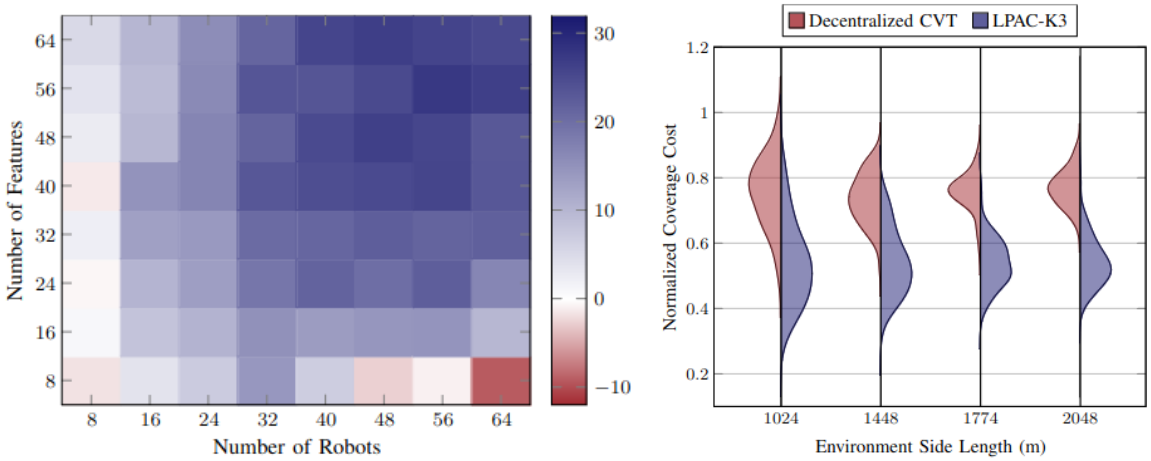


Figure 2. (Left) Evaluation of the LPAC-K3 model on environments with varying numbers of features and robots (left) and environment size (right). These results show that the LPAC model is able to generalize to larger environments with a larger number of robots and features, even though the model is trained on environments with a smaller number of robots and features.

Project Title: 29_ROBOT COMM – Deployment of Autonomous Ground Robots to Facilitate Communication

Thrust(s): Thrust 2 / Thrust 3 **ARL / TRL:** 3 / 4

Faculty Investigators: Alejandro Ribeiro, Vijay Kumar (Penn), David Cappelleri (Purdue), Stefano Carpin (Merced)

Researcher(s): Agarwal, Vatnsdal, Owerko (Penn)

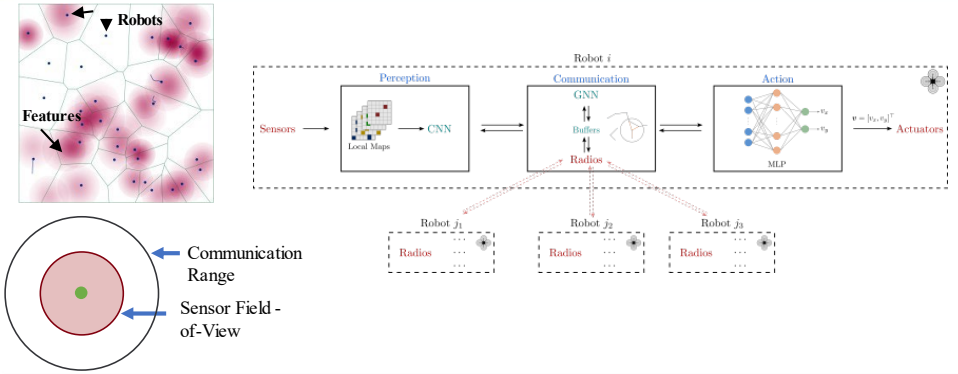
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PROJECT OVERVIEW

Navigating a swarm of robots through an environment to achieve a common collaborative goal is a challenging problem, especially when the sensing and communication capabilities of the robots are limited. These problems require high-fidelity algorithms comprising three key modules: perception, action, and communication, which are executed in a feedback loop, i.e., the Perception-Action-Communication (PAC) loop. A decentralized system does not suffer from a communication bottleneck and is scalable to large swarms and environments.

Robot swarms are relevant in agriculture industries for routine tasks such as inspection for weeds and pests, estimating harvest yield, and analyzing health of crops. They provide (i) ability to continuously adapt to dynamic environment (ii) rapid coverage of large fields, and (iii) repeatability in information acquisition for reliable longitudinal data analysis.

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

A learnable PAC system comprises three tightly integrated modules. These modules run independently on each robot in a decentralized system.

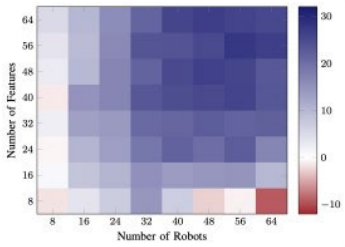
The **perception** module is responsible for getting the sensor data and creating local maps. A Convolution Neural Network (CNN) is used to process local maps to generate input features for the GNN. Additional tasks include semantic mapping, object detection, and localization.

The **communication** module is the collaborative unit responsible for exchanging information. The GNN in the module decides what information must be communicated and how to incorporate information received from neighboring robots to make inferences.

The **action** module uses a shallow MLP to process the output of the GNN and generate actions, usually velocities or positions, that are then sent to the actuators of the robot.

KEY ACCOMPLISHMENTS TO-DATE

(a) LPAC outperforms baselines. It learns to share abstract information, which is challenging to design otherwise.
(b) LPAC generalizes to environments with varying numbers of robots and features. Transfers well to large systems with up to hundreds of robots and features
(c) Training on synthetic datasets with random features transfers well to real-world datasets without retraining.
(d) Conducted an experiment with 5 aerial robots and 2 ground robots covering 10 features in a 100 m by 60 m area. Used asynchronous communication .



YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 32_SPRAY SYS: Improving the Efficiency of Crop Input Applications Using Advanced Spray Systems
Thrust(s): Thrust 1 – Agricultural Sensors Systems / Thrust 3 – Agricultural Response Systems
Lead Faculty Investigator: Ian Small (UF)
Co-Investigator(s): Alina Zare (UF), William Eisenstadt (UF)
Researcher(s): Barocco, Hampton (PhD/UF)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems
TRL #: 2 – Technology concept and/or application formulated.
ARL #: 1 – Conceived by the IoT4Ag project team

OBJECTIVES & CENTER ALIGNMENT: The objective of this project is to develop prediction models and decision support tools using an integrated system of sensors to inform the precision management of crop health and diseases. Novel sensor and AI detection technologies are being developed through Project 18 to augment or improve the efficiency of conventional data collection for crop models and decision support systems. Two primary areas of research were originally proposed: 1) optimization of in-season application of nitrogen fertilizer on cotton and 2) optimization of in-season application of crop protection inputs for diseases on peanut. The current goal evolved to focus on objective two for peanut as a case study. Work towards using point spectra for monitoring cotton foliar nitrate levels is reported in Project 18 for contribution to the Sentinel system.

KEY PROJECT ACCOMPLISHMENT IN THIS PERIOD:
Peanut field trials at the UF/IFAS NFREC in Quincy and Live Oak have been designed and are being conducted to evaluate winter field management practices, in-field environmental sensor data, and multispectral drone imagery as predictive inputs for pathogen activity, disease development, and plant health (Figure 1).

TESTBED & JOINT-OP ACTIVITY:
This project contributes to Testbed 2 (Integrated Systems for Precision Farming of Row Crops) and Joint Op 3 (Integrated Systems to Mitigate Crop Loss Due to Diseases and Pests). Peanut disease field trials for the 2023 season were completed. Disease assessments were conducted periodically throughout the season. Corresponding drone flights were conducted by the industry partner AgriBugs to collect multispectral imagery, which will be used to quantify peanut disease defoliation using the UAS remote sensing model developed and reported in Project 18 Sentinel. Winter field management treatments, including different cover crops and tillage practices, have been completed for 2024 season. In-field environmental sensor data was collected during the 2023 peanut season and the 2023-24 winter crop season, and stations were re-installed after peanut planting in early June 2024. The in-field environmental sensor stations (Figure 2) monitor volumetric water content (VWC), electrical conductivity (EC), and temperature (T) in the upper soil layer (-5 cm) and temperature (T), relative humidity (RH), and leaf moisture within the canopy (15 cm). The workshop "Capturing the Wind: A Guided Session on Low-Cost Airborne Sampler Construction and Use" held at the American Phytopathological Society (APS) Plant

Health 2023 conference on August 12 in Denver was attended (Barocco) to learn from other plant pathologist interested in spore traps for disease ecology and epidemiology research. Components for a rotating rod spore trap were assembled at the workshop, and methods for mounting in a field trial at the NFREC was explored for future implementation (Figure 3).

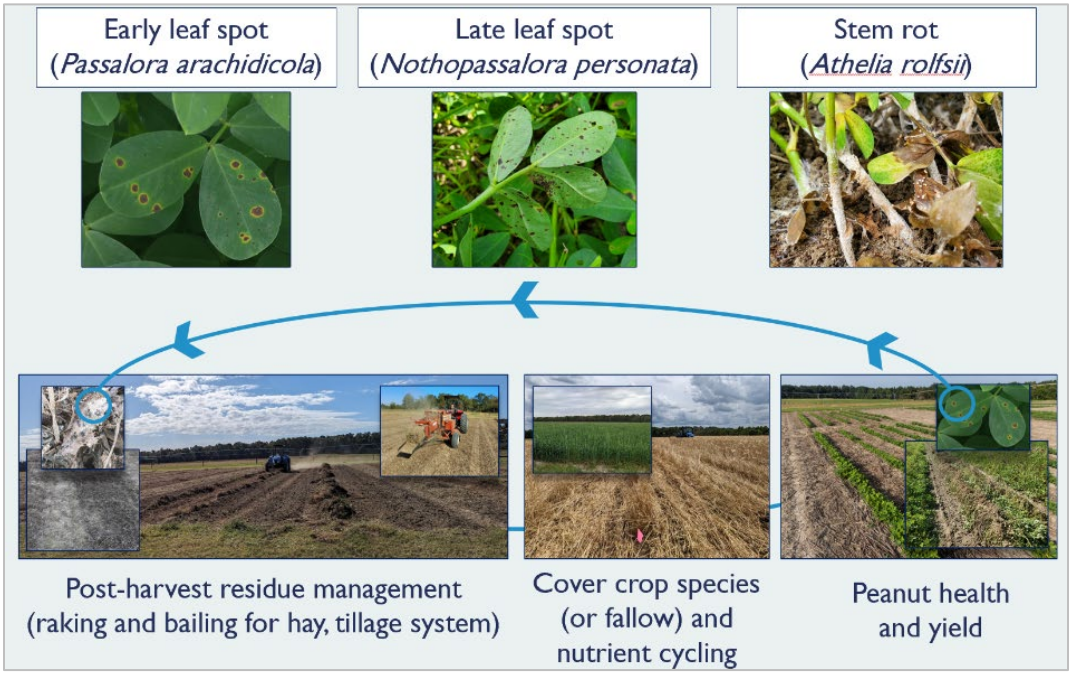


Figure 1. Peanut fungal diseases known to cause economic yield loss that survive within fields between seasons and a diagram of within-field peanut leaf spot pathogen survival and disease infection cycle in the context of a winter field management trial at the NFREC in Quincy, FL.



Figure 2. In-field station with commercial (METER Group, Inc.) environmental sensors installed in an emerging triticale cover crop for a peanut trial at the NFREC in Live Oak, FL.



Figure 3. A rotating rod spore trap installed at the NFREC in Quincy, FL.

Project Title: 32_SPRAY SYS: Improving the Efficiency of Crop Input Applications Using Advanced Spray

Thrust(s): Thrust 1 / Thrust 3 **ARL / TRL:** 1 / 2

Faculty Investigators: Ian Small, Alina Zare, William Eisenstadt (Florida)

Researcher(s): Barocco , Hampton (Florida)

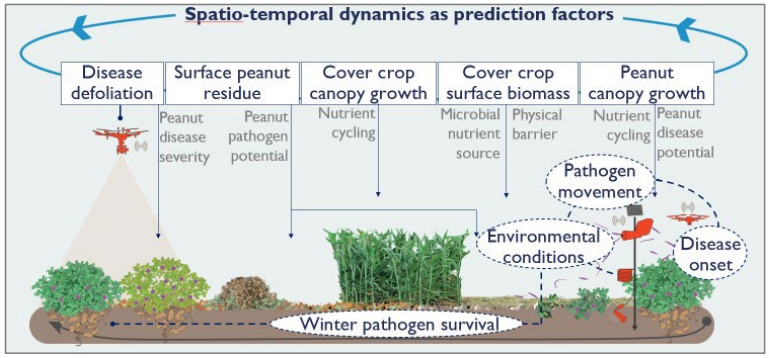
IoT4Ag
The Internet of Things for Precision Agriculture
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PROJECT OVERVIEW

The objective of this project is to develop prediction models and decision support tools using an integrated system of sensors to inform the precision management of crop health and diseases. Novel sensor and AI detection technologies are being developed through Project 18 to augment or improve the efficiency of conventional data collection for crop models and decision support systems. Two primary areas of research were originally proposed: 1) optimization of in-season application of nitrogen fertilizer on cotton and 2) optimization of in -season application of crop protection inputs for diseases on peanut. The current goal evolved to focus on objective two for peanut as a case study.

(Work towards using point spectra for monitoring cotton foliar nitrate levels is reported in Project 18 for contribution to the Sentinel system.)

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

This project contributes to Testbed 2 and Joint Op 3. A barrier to this research is dependency on sensor systems being developed through Project 18 and other IoT4Ag projects. Research emphasis is on holistic plant health management for protection against fungal diseases caused by pathogens that survive within fields between seasons. These fungal diseases are the primary drivers of fungicide input decisions. The goal is to better understand the factors affecting pathogen behavior and disease cycles through empirical studies and computer simulation modeling. Empirical data collection will be a combination of conventional methods and novel uses of currently available sensor technologies. Novel sensor, AI detection, and automated data integration technologies developed in Project 18 and other relevant IoT4Ag projects will be incorporated in future work when mature.

KEY ACCOMPLISHMENTS TO-DATE

- Peanut field trials at the UF/IFAS NFREC in Quincy and Live Oak have been designed and are being conducted to evaluate winter field management practices, in-field environmental sensor data, and multispectral drone imagery as predictive inputs for pathogen activity, disease development, and plant health
- Publications in peanut disease modeling including the following:

  Sanjel, S., Colee, J., Barocco, R., Dufault, N.S., Tillman, B., Punja, Z. K., Seepaul, R., Small, I.M. 2023. Environmental factors influencing stem rot development in peanut: predictors and action thresholds for disease management. Phytopathology 114 (2) 393-404. https://doi.org/10.1094/PHYTO-05-23-0164-R

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 33_NUTRIENT MANAGEMENT: A new paradigm for nutrient management in the US enabled by sensing, IoT, and prediction modeling
Thrust(s): Thrust 3 – Agricultural Response Systems / Thrust 1 – Agricultural Sensor Systems
Lead Faculty Investigator: Charlie Messina (Florida)
Co-Investigator(s): Melba Crawford (Purdue); Vivek Sharma (Florida)
Researcher(s): Maghsood, Quijano, Cabrera (PhD/Purdue), Hisse (Postdoc/Florida), Tiwari (Staff/Florida)

LOCATION ON 3-PLANE DIAGRAM: 1. Fundamental knowledge
TRL #: 3 **ARL #:** 3
OBJECTIVES & CENTER ALIGNMENT:
This project seeks to evaluate an alternative paradigm to N management in row crop agriculture. The project hypothesizes that the availability of IoT can enable a shift in mindsets, agricultural system design and decision-making. In today's paradigm, farmers and industry attempt to predict the outcomes of a complex system with low rates of success. This is demonstrated by the high rates of N loss to the environment in agricultural systems and associated externalities (negative side effects of agricultural production that affects society and are not included in the cost of the goods.) In the alternative paradigm, the decision maker manages the agricultural complex system by taking corrective actions, and thus reduce externalities. The **objective** of this project is *to develop and demonstrate a self-regulatory IoT-enabled approach to nutrient management where self-regulation is achieved through interaction among stakeholders*. The **output** of this project is *the business logic for the integration of IoT with decision-making*. A key **outcome** is *the opportunity to transform agriculture to continue increasing food production while reducing externalities.*

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD
Empirical Studies. We have initiated field trials in Florida at the experiment station located in Hastings (see report for project 20 Corn Mass/N2 for data collected at Purdue) and NFREC-SV, Live Oak, FL. Both are satellite place from the core North Florida Research Center where most activities are conducted. At Hasting, the field trial was planted after Potatoes, a crop that it is heavily fertilized and may contribute to high externalities in the form of N loss to ground water and nitrogen oxide emissions. The choice of planting date was informed by local management practices and interaction with growers who are in contact with the research station manager. This late planting delayed the project at the expense of brining realism to the experiment. Early planting will be used in 2025 to complete the project on time for final report.

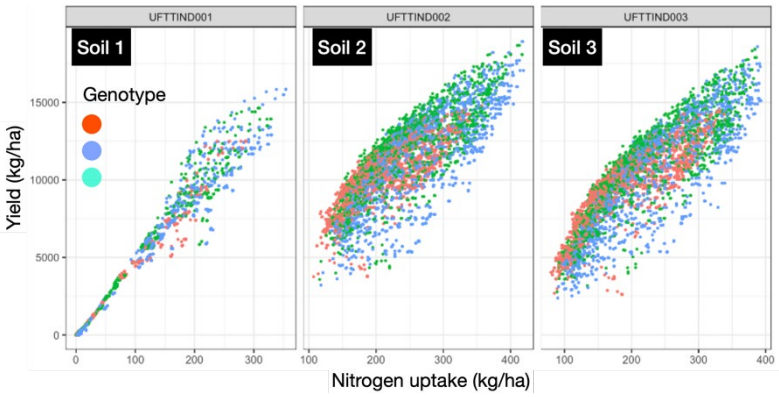


Fig 1. Simulated yield response to nitrogen uptake by soil type and genotype. Note the genotype (variety) x soil interaction.

At, Live Oak, FL, project is focused on two themes, (i) Evaluate the effectiveness of precision irrigation and nutrient technologies such as VRI and VRN

management with pivot-mounted multispectral and thermal imaging sensors for irrigation and nutrient management, and (ii) Development of Machine Learning Models based on Spectral Indices to Determine the Leaf Nitrogen Content of Maize.

Modeling studies

We have generalized the agent-based model to simulate conditions are different from Florida environments and more aligned with environmental conditions of the Midwest corn belt. This is an important finding since soil x genotype interactions were found and thus necessary to include in the new functionality of the model bringing more opportunities for the Midwest farmer to leverage IoT and sensor technology to manage production fields. In figure 1 we show the yield response to N by soil type. In addition, generative adversarial network modeling is used to convert visual information captured by an RGB camera into temperature values represented by thermal images so we can estimate soil irrigation levels.

Spatiotemporal modeling for sensor optimization deployment

The Soil and Water Assessment Tool (SWAT) is a process-based dynamical hydrology model. Because of the impact of soil temperature in N mineralization and loses to the atmosphere we verified that the model accurately soil temperature during freezing-thawing process, which was remarkably good relative to other models. Then SWAT was employed to simulate the distribution of soil moisture and nutrient levels at the Little River basin in Georgia. To enhance model accuracy, we integrated a Long Short-Term Memory (LSTM), a form of Deep Learning (DL) with SWAT. Figure 2A shows the integration approach. This integration addresses the challenges posed by the heterogeneity and complexity of watershed behaviors. DL methods can detect patterns across diverse sites (sensors/HRUs) that might not be readily apparent through SWAT alone. This hybrid modeling approach harnesses the strengths of both SWAT and DL, resulting in more accurate and comprehensive soil moisture (Fig. 2B,C; base r^2=0.36 vs +DL r^2=0.52). By evaluating the model's performance, we can identify optimal placements for soil moisture sensor deployments based on the largest gain for error correction. This prioritization enhances landscape monitoring and ensures effective sensor allocation, ultimately leading to better-informed decisions for field to watershed management.

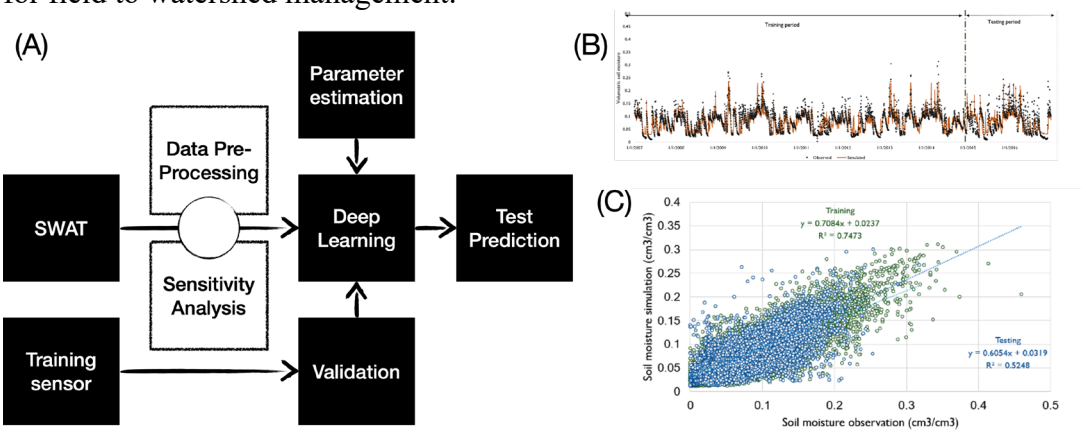


Figure 2. Schematic of the process used to fuse the biophysical model Soil and Water Assessment Tool (SWAT) with deep learning to improve for soil moisture predictions.

TESTBED & JOINT-OP ACTIVITY:

This project is core to the N management join-op activity, and was executed at two testbeds.

Project Title: 33_NUTRIENT MANAGEMENT: A new paradigm for nutrient management in the US enabled by sensing, IoT and prediction modeling

Thrust(s): Thrust 3 – Agricultural Response Systems / Thrust 1 – Agricultural Sensor Systems **ARL / TRL:** 3 / 3

Faculty Investigators: Charlie Messina, Vivek Sharma (Florida), Melba Crawford (Purdue)

Researcher(s): Magshood,, Cabrera, Hisse, Tiwari (Florida), Quijano (Purdue)

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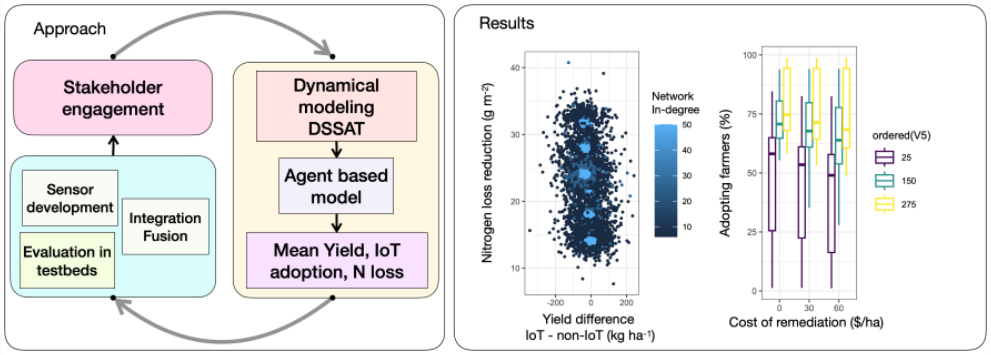
PROJECT OVERVIEW

This project takes place at the nexus of sensing, modeling & field research, and decision making. Thus, it operates at the core of the Joint Ops creating a space for discussing sensing, prediction and decision modelling needs.

Phase I contributed to create the framework that brings models, data and decisions together (plant and agent-based models).

Phase II initiated evaluation of the framework in testbed, which will improve iteratively. Also, developed an approach that fused a mechanistic dynamical model with deep learning to optimize the deployment of sensors in the landscape, inform sensor design, and thus reduce use of water and nutrients. Key questions remains about the performance of the Fusion approach, how to improve it linking with remote sensing observations, What sensors type/s are needed?, what is the optimal frequency to observe the system?

SUMMARY FIGURE



RESEARCH APPROACH & BARRIERS

Joint Ops Nitrogen. Simulation and concept development to demonstrate feasibility of a new paradigm enabled by IoT in agriculture to manage nitrogen in crop production.

Testbed linkage. field evaluation of the concepts and models, and to iteratively improve sensing capabilities best suited to deliver the value to the stakeholders. Filed experimentation was initiated and models significantly improved that will enable in-silico experimentation and refinement of sensor needs (number, placement,, etc)

Barriers to advance the project are: 1) environmental because of the dependence of outcomes of field research on weather conditions, 2) social because of the need to collaborate with stakeholders that may not yet see the economic opportunity but a threat to regulation, need to work across disciplines

KEY ACCOMPLISHMENTS TO-DATE

Year 2. DSSAT models implemented in HiperGator and enabled simulation studies

Year 3. Study demonstrating the framework completed and shared with stakeholders and the scientific community. We received positive feedback.

Results for case study shows the opportunity to maintain productivity while reducing externalities. The expected long-term amount on nitrogen reduction could reach 50% of the nitrogen used by the crop; current nitrogen use efficiency range from 50-75%.

Transition project from TRL1 to TRL 3. Field evaluation started in tested.

Year 4. Fusion of SWAT and Deep learning demonstrate increased prediction accuracy. This approach can improve deployment of sensors, and thus reduction of water and nutrient use/ use efficiency

YR4 PROJECT UPDATE: July 1, 2023 – June 30, 2024

Project Title: 34_STAKEHOLDER ENGAGEMENT: Community Engagement for Internet of Things for Precision Agriculture (IoT4Ag) NSF Engineering Research Center
Thrust(s): EWD, DCI and IE
Lead Faculty Investigator: Kathryn Stofer (UF)
Co-Investigator(s): Sebastian Galindo (UF)
Researcher(s): Nickerson (PhD/UF), Naranjo (MS/UF)

LOCATION ON 3-PLANE DIAGRAM: 3. Systems (primarily)
TRL #: N/A **ARL #:** N/A

OBJECTIVES & CENTER ALIGNMENT:
The project supports the translation of research into practice through strategic collaborations and engagement with various community partners and interest holders, especially farmers. Additional interest holders in the Center activities include internal Center personnel, local public audiences, and K-12 and higher education students, especially those at minority-serving institutions. We had four objectives: 1) enhance stakeholder engagement, primarily with end-user farmers through evidence-based approaches designed in concert with farmers and evaluated for impact; 2) connect with participating institutions to identify key leaders for engagement efforts; 3) facilitate professional development for internal and external groups; and 4) create a unified Engagement Plan with evaluation to enhance Center impact.

Objective 1. In Year 4, we began to align planned farmer-focused engagement and technology /adoption readiness level rubric development with the work of Project 28: Tech Adoption, through collaboration with faculty Keske and Yeo. We report updates on that work in Project 28. Additionally, we assisted the Center's Engineering Workforce Development (EWD) and Diversity and Culture of Inclusion (DCI) foundational components by building relationships with particular groups of farmers, producers, and community-based broker organizations who connect with key parts of the agricultural system but not necessarily commodity farmers. We connected with the Latino Farmworkers Alliance; AgrAbility, serving veterans and farmers with disabilities; and the Community Alliance for Family Farms. Relationships with those groups are helping expand the potential use cases of current IoT4Ag technology in development while laying groundwork for bringing perspectives into the technology design process (along with Project 28 moving forward).

Objective 2. Naranjo had discussions with a variety of agricultural interest holders, including individuals, Extension personnel, government, and non-profits (in conjunction with Project 28), and we devised a plan for building long-term key leaders for engagement efforts at partner institutions including community and commodity groups. We learned of other regional group leaders, such as the Latino Farmers Alliance, who will need to be our liaisons with specific communities. With these liaisons, we will move forward with long-term engagement around widespread diffusion of innovations via professional development for agricultural personnel through formalized IoT4Ag roles for Cooperative Extension personnel and the liaisons.

Objective 3. We held two webinars for external audiences, one aimed more narrowly at nationwide Cooperative Extension personnel and one more farmer-focused, designed to introduce the

technology to more farmers and invite them to participate as advisors on technology design. We also discussed the project in a presentation with AgrAbility. Internally, we created practitioner-focused guides on engagement; we have one submitted peer-reviewed article on engagement with groups at Career Expos, another submitted on farmer engagement around precision agriculture. We also began leading the UF Impact team meetings as of January 2024. These meetings allow us to dive deeper into UF activities as springboards to develop support for all Center personnel. We supported a new relationship with Disney to integrate IoT4Ag technology into their Land exhibit at Epcot Center; in the short-term, we think we will be able to promote the existence of the partnership as part of our engagement, and in the longer-term we may be able to have a small display or exhibit in Epcot promoting IoT4Ag.

Objective 4. To strengthen the EWD and DCI components, the Center hired Kristin Field, Director of Education and Inclusivity in Spring 2024. Project 34/Stofer and Galindo as co-leads of Stakeholder Engagement, work with Field and EWD and DCI leads Bidstrup Allen, Yeo, and Arratia to coordinate efforts through a unified engagement plan. The EWD and DCI teams completed a realignment of signature programs based on advisory board input which will guide the overall engagement plan. As part of the plan, we will work with Boyce and the external evaluation team to develop and implement evaluation tools for use at engagement events to examine what external audiences learn and prepare Center personnel on how to both facilitate engagement and evaluate its effectiveness. Such evaluation will complement the internal project evaluation activities and ensure a comprehensive Center evaluation. We hired a communications technician in summer 2024 to support engagement through further developing public- and farmer-facing activities to facilitate engagement at events outside of structured classroom settings or workshops, such as festivals. The activities both expand the topics covered by lessons created via RET participants (new activities include explanations of internet/communication technologies, aflatoxin detection, and also crops the Center studies) and prepare materials in ready-to-use sets. Copies of each set will be sent to each institution.

KEY PROJECT ACCOMPLISHMENTS IN THIS PERIOD:

1) Alignment and collaboration with Project 28, and established relationships with broker groups. 2) Identification of long-term strategy for farmer professional development across Center institutions. 3) Webinars for external audiences, peer-reviewed practitioner guidance for internal audiences. 4) Integration of Stakeholder Engagement work to support the new Director of Education and Inclusivity, the realigned EWD and DCI signature programs, and evaluation.

TESTBED & JOINT-OP ACTIVITY:

Our project supports all testbed and JointOp Activity. We have started discussions to integrate IoT4Ag technology in the Corn STEP program at the UF Testbed to facilitate farmer interaction with developing technologies to gather feedback. As the SPRING devices come online at testbeds as part of our EWD/DCI signature programs, we are devising materials to support and promote the use of the devices and data for both farmers directly and workforce and community audiences. We revised our engagement content approach to focus on JointOps as well as Convergent Research Thrusts to promote the center's work. For example, Naranjo's work identified that some farmers may be tired of talking about nitrogen, particularly in Florida, but focusing on internet may better resonate, while California farmers may still focus on water.

Project Title: 34_STAKEHOLDER ENGAGEMENT

Thrust(s): EWD, DCI and IE

ARL / TRL: N/A

Faculty Investigators: Kathryn A. Stofer, Sebastian Galindo (Florida)

Researcher(s): Nickerson, Naranjo (Florida)

IoT4Ag
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PROJECT OVERVIEW

The Community Engagement Project supports the WFD and DCI foundational components by identifying key leaders for engagement efforts; enhancing farmer/researcher engagement through approaches co-designed with farmers and researchers and evaluated for impact; facilitating internal and external professional development and building tools to assist engagement; and enhancing the existing Outreach and Engagement Plan to evaluate and strengthen impact of the Iot4Ag Center.

SUMMARY FIGURE

Interest Holder	What they want (and Why)
Owner/manager	Cheap, multi-purpose (High debt loads, Stewardship, lots of crops)
Operators	Easy to use/maintain, accurate (They're held responsible when something goes wrong)
Government	Food production (Security and sovereignty)
Industry	Groundbreaking and adoptable (Profit)

RESEARCH APPROACH & BARRIERS

Nickerson, Naranjo, and Stofer attended a variety of farmer and community events to gather input and promote IoT4Ag; an REU student was recruited at one. Online group engagement listening sessions proved infeasible, so Naranjo began interviews with farmers and additional interest holders instead. Naranjo also conducted a literature review on barriers to precision agriculture adoption. Stofer met 1-1 with Rios from the Latino Farmworkers' alliance and forged a partnership to engage those farmers going forward. We identified opportunities to engage farmers with IoT4Ag tech through other events using testbed facilities. We gather information about farmer interest in JointOps and or thrusts as well as which crops beyond commodities might have an interest in IoT4Ag technology. We hired a communications technician summer 2024 to put together kits with activities and instructions to facilitate engagement at local events.

KEY ACCOMPLISHMENTS TO-DATE

Aligned work on farmer engagement with Project 28: Tech Adoption
Established relationships with 3 farmer broker groups.
Identified long-term strategy for farmer professional development across Center institutions.

External audience activities: Two webinars, 1 presentation for external audiences
Internal audience activities: Submitted 2 peer-reviewed publications on guidance for researchers to take part in community engagement

Integrated community engagement work to support the new Director of Education and realigned EWD and DCI signature programs

APPENDIX VIII. BIBLIOGRAPHY OF PUBLICATIONS

Year 1: 9.1.2020 to 6.30.2021

Thrust 1 ***(core / centered supported)***

Thrust 2 – secondary**:** Kagan, C.R., Arnold, D.P., Allen, M.G., & Olsson, R.H. "IoT4Ag: MEMS-enabled distributed sensing, communications, and information systems for the internet of things for precision agriculture," Proc. 34th IEEE Intl. Conf. Micro Electro Mechanical Systems (MEMS 2021), pp. 350-353, January 2021. doi: 10.1109/MEMS51782.2021.9375346.

Thrust 1 ***(associated)***

Clohessy, J.W., Sanjel, S., O'Brien, G.K., Barocco, R., Kumar, S., Adkins, S., Tillman, B., Wright, D.L., & Small, I.M. "Development of a high-throughput plant disease symptom severity assessment tool using machine learning image analysis and integrated geolocation," Computers and Electronics in Agriculture, vol. 184, pp. 1-11, May 2021, doi: 10.1016/j.compag.2021.106089.

Guo, J., Kim, J., Yang, S., Xu, J., Choi, Y.C., Stein, A., Murray, C.B., Kotov, N.A., & Kagan, C.R. "Broadband Circular Polarizers via Coupling in 3D Plasmonic Meta-Atom Arrays," ACS Photonics, vol. 8, no. 5, pp. 1286-1292, April 2021, doi: 10.1016/j.compag.2021.106089.

Thrust 3 – secondary: Kan, X., Thayer, T.C., Carpin, S., & Karydis, K., "Task Planning on Stochastic Aisle Graphs for Precision Agriculture," IEEE Robotics and Automation Letters, vol. 6, no. 2, pp. 3287-3294, April 2021, doi: 10.48550/arXiv.2102.01825.

Thrust 3 – secondary: Nardari, G.V., Cohen, A., Chen, S.W., Liu, X., Arcot, V., Romero, R.A.F., & Kumar, V. "Place Recognition in Forest with Urquhart Tessellations," IEEE Robotics and Automation Letters (RA-L), pp. 1-9, November 2020. https://arxiv.org/abs/2010.03026v2

Thrust 3 – secondary: Olmedo Pico, L.B., & Vyn, T.J. "Dry Matter Gains in Maize Kernels Are Dependent on Their Nitrogen Accumulation Rates and Duration during Grain Filling," Plants, vol. 10, no. 6, pp. 1-18, June 2021, doi: 10.3390/plants10061222.

Sidhu, S.S, Wright, D.L, George, S., & Small, I.M. "Nitrogen calibration strip: An on-farm tool to further reduce N requirements in cotton on an integrated crop-livestock rotation system," Agronomy Journal, May 2021, doi: 10.1002/agj2.20730.

Thrust 3 – secondary: Thayer, T.C., & Carpin, S. "Solving Large-scale Stochastic Orienteering Problems with Aggregation," 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 2452-2458, February 2021, doi: 10.1109/IROS45743.2020.9340899.

Thrust 3 – secondary: Thayer, T.C., & Carpin, S. "An Adaptive Method for the Stochastic Orienteering Problem," IEEE Robotics and Automation Letters, vol. 6, no. 2, pp. 4185-4192, April 2021, doi: 10.1109/LRA.2021.3068699.

Thrust 2 ***(core / centered supported)***

Chou, T.H., Michelusi, N., Love, D.J., & Krogmeier, J.V. "Fast Position-Aided MIMO Beam Training via Noisy Tensor Completion," in IEEE Journal of Selected Topics in Signal Processing, vol. 15, no. 3, pp. 774-788, April 2021, doi: 10.1109/JSTSP.2021.3063837.

Halim, M.A., Smith, S.E., Rendon-Hernandez, A.A., & Arnold, D. P. "Electromechanical modeling and experimental validation of a dual-transduction electrodynamic wireless power receiver," Proc. 21st International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers 2021), vol. 21, pp. 1335–1338, June 2021. doi: 10.1109/Transducers50396.2021.9495543.

Oh, M.S., Hosseinalipour, S., Kim, T., Brinton, C.G., & Love, D.J. "Channel Estimation via Successive Denoising in MIMO OFDM Systems: A Reinforcement Learning Approach," *ICC 2021 - IEEE International Conference on Communications*, 2021, pp. 1-6, doi: 10.1109/ICC42927.2021.9500671.

Sahay, R., Love, D.J., & Brinton, C.G. "Robust Automatic Modulation Classification in the Presence of Adversarial Attacks," 2021 55th Annual Conference on Information Sciences and Systems (CISS), 2021, pp. 1-6, doi: 10.1109/CISS50987.2021.9400326.

Thrust 2 ***(associated)***

Liu, H., Reibman, A., Ault, A., & Krogmeier, J. "Spatial segmentation for processing videos for farming automation," *Computers and Electronics in Agriculture*, Vol. 184, May 2021. doi: 10.1016.j.compag.2021.106095.

Smith, S.E., Halim, M.A., Chyczewski, S.T., Rendon-Hernandez, A.A., & Arnold, D.P. "A wirelessly rechargeable AA battery using electrodynamic wireless power transmission," Energies, vol. 14, no. 9, pp. 1-14, April 2021, doi: 10.3390/en14092368.

Wang, Y., Liu, H., Krogmeier, J., Buckmaster, D., & Reibman, A. "ISOBlue HD: An Open-Source Platform for Collecting Context-Rich Agricultural Machinery Datasets." *Sensors Journal*. 20(20, 5768, October 2020. doi: 10.3390/s20205768.

Zhang, Y., Tan, J.A., Dorbert, B,M., Anderson, C.R., & Krogmeier, J.V. "Simulation-Aided Measurement-Based Channel Modeling for Propagation at 28 GHz in a Coniferous Forest," GLOBECOM 2020 - 2020 IEEE Global Communications Conference, pp. 1-6, January 2021, doi: 10.1109/GLOBECOM42002.2020.9322386.

Thrust 1 – secondary: Venkatesh, V., Yang, Q., Zhang, J., Pikul, J.H., & Allen, M.G. "Fabrication and Characterization of Evaporated Zinc Anodes for Small-Scale Zinc-Air Batteries." *The 21st International Conference on Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS).* Virtual, Online. June 20-24, 2021. doi: 10.1109/Transducers50396.2021.9495470.

Thrust 3 ***(associated)***

Thrust 1 – secondary: Kantaros, Y., Schlotfeldt, B., Atanasoy, N., & Pappas, G.J. "Sampling-based planning for non-myopic multi-robot information gathering," Autonomous Robots, June 2021, doi: doi.org/10.1007/s10514-021-09995-4.

Thrust 1 – secondary: Keske, C. M. H., Arnold, P., Cross, J. E., & Bastian, C.T. "Does Conservation Ethic Include Intergenerational Bequest? A Random Utility Model Analysis of Conservation Easements and Agricultural Landowners," Rural Sociology, vol. 0, no. 0, pp. 1-25, February 2021, doi: 10.1111/ruso.12370.

Year 2: 7.1.2021 to 6.30.2022

Center-Wide ***(core / centered supported)***

Kagan, C.R., Arnold, D.P., Cappelleri, D.J., Keske, C.M., & Turner, K.T. "Special report: The Internet of Things for Precision Agriculture (IoT4Ag)." *Computers and Electronics in Agriculture*, Vol. 196, pp. 106742, May 2022. doi: 10.1016/j.compag.2022.106742.

Thrust 1 ***(core / centered supported)***

Thrust 3 – secondary: Jarin-Lipschitz, L., Liu, X., Tao, Y., & Kumar, V. "Experiments in Adaptive Replanning for Fast Autonomous Flight in Forests." *2022 IEEE International Conference on Robotics and Automation (ICRA)*. Philadelphia, Pennsylvania. May 23-27, 2022. doi: 10.1109/ICRA46639.2022.9812235.

Thrust 3 – secondary: Liu, X., Chen, S.W., Nardari, G.V., Qu, C., Cladera Ojeda, F., Taylor C.J., & Kumar, V. "Challenges and Opportunities for Autonomous Micro-UAVs in Precision Agriculture." *IEEE Micro*, Vol. 42, No. 1, pp. 61-68, February 2022. doi: 10.1109/MM.2021.3134744.

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Thrust 1 ***(associated)***

Thrust 3 – secondary: Afsah-Hejri L., Toudeshki, A., Homayouni, T., Mehrazi, S., Gholami Pareh, A., Gordon, P., & Ehsani, R. "Potential of ozonated-air (OA) application to reduce the weight and volume loss in fresh figs (Ficus carica L.)." *Posthconarvest Biology and Technology*, Vol. 180, pp. 111631, October 2021. doi: 10.1016/j.postharvbio.2021.111631.

Barocco, R.L., Sanjel, S., Dufault, N.S., Barrett, C., Broughton, B., Wright, D.L., & Small, I.M. "Peanut disease epidemiology under dynamic microclimate conditions and management practices in North Florida." *Plant Disease,* October 2021. doi: 10.1094/PDIS-11-20-2390-RE.

Thrust 3 – secondary: Carpin, S. "Scheduling problems for robotics in precision agriculture". *Proceedings of the 2022 IEEE International Symposium on Circuits and Systems*. Austin, Texas. May 28 - June 1, 2022. https://ieeexplore.ieee.org/document/9937482

Thrust 2 – secondary: Manish, R., An, Z., Habib, A., Tuinstra, M.R., & Cappelleri, D.J. "AgBug: Agricultural Robotic Platform for In-Row and Under Canopy Crop Monitoring and Assessment." *Proceedings of the ASME 2021 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 8B: 45th Mechanisms and Robotics Conference (MR)*. Virtual, Online. August 17-19, 2021. doi: 10.1115/DETC2021-68143.

Thrust 3 – secondary: Narayan, S., Paulos, J., Chen S.W., Manjanna, S., & Kumar, V. "Combined Routing and Scheduling of Heterogeneous Transport and Service Agents," *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. Prague, Czech Republic. September 27-October 1, 2021. doi: 10.1109/IROS51168.2021.9636684.

Thrust 2 – secondary: Olmedo Pico, L.B., Zhang, C., & Vyn, T.J., 2021. "The central role of ear nitrogen uptake in maize endosperm cell and kernel weight determination during the lag period." *Fields Crop Research*, Vol. 273, pp. 108285, November 2021. doi: 10.1016/j.fcr.2021.108285.

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Thrust 1 – secondary: Schell, E.V., Murphy, J.G., Hawkings, J.R., Plante, A.F., Allen, M.G. "Degradable Mo-Based Phosphate Sensor for In-Soil Agricultural Monitoring," *2023 IEEE SENSORS*, Vienna, Austria, 2023, pp. 1-4, doi: 10.1109/SENSORS56945.2023.10325322.

Thrust 2 ***(associated)***

Thrust 1 – secondary: Huang, Y., Zhang, J., Yang, Q., Venkatesh, V., Pikul, J., Allen, M., Bidstrup-Allen, S. "Mechanistic Study of Hydroxide Ion Consumption in Ultralean PVA Hydrogel Electrolytes for High-Energy-Density Micro Zinc-Air Batteries". *Journal of The Electrochemical Society*. 2023. 170. doi: 10.1149/1945-7111/ad02c0.

Thrust 3 ***(core / center supported)***

Thrust 2 – secondary: Basir, S., Noel, S., Buckmaster, D., Ashik-E-Rabbani, M. "Enhancing Subsurface Soil Moisture Forecasting: A Long Short-Term Memory Network Model Using Weather Data" *2024 Agriculture* 14, no. 3: 333. https://doi.org/10.3390/agriculture14030333

Thrust 2 – secondary: Deb, A., Kim, K., & Cappelleri, D.J. "Deep Learning-based Leaf Detection for Robotic Physical Sampling with P-AgBot", IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI, October 1 – 5, 2023. https://doi.org/10.1109/IROS55552.2023.10341516.

Thrust 1 – secondary: Messina, C. D., Gho, C., Hammer, G. L., Tang T., & Cooper, M. "Two decades of harnessing standing genetic variation for physiological traits to improve drought tolerance in maize". *Journal of Experimental Botany*, Volume 74, Issue 16, 1 September 2023, Pages 4847–4861, https://doi.org/10.1093/jxb/erad231

Thrust 1 – secondary: Nesslage, J., Barreto, B.L., Weingram, A., Hestir, E. "A Machine Learning Approach for High Resolution Fractional Vegetation Cover Estimation Using Planet Cubesat and RGB Drone Data Fusion". *IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Sym*posium, Pasadena, CA, USA, 2023, pp. 4879-4882, doi: 10.1109/IGARSS52108.2023.10283449. https://ieeexplore.ieee.org/abstract/document/10283449

Thrust 1 – secondary: Pathak, H., Buckmaster, D., Messina, C., Wang, D. "Crop growth model: Optimal Application of Nitrogen Fertilizer in Corn for Economic Returns and Environmental Sustainability". *In 2023 ASABE Annual International Meeting (p. 1). American Society of Agricultural and Biological Engineers*. doi: 10.13031/aim.20230042. https://elibrary.asabe.org/abstract.asp?aid=54131&t=3&dabs=Y&redir=&redirType=

Thrust 1 – secondary: Pathak, H., Zhang, Y., Sprague, N. C., Buckmaster, D. R., Evans, J. T., Chaterji, S., & Krogmeier, J. V. "Autonomous Navigation in Digital Agriculture: Using the Segment-Anything-Model for Corn Row Identification". In 2023 IEEE India Geoscience and Remote Sensing Symposium (InGARSS), December 2023, (pp. 1-4). IEEE. doi: 10.1109/InGARSS59135.2023.10490329. https://ieeexplore.ieee.org/abstract/document/10490329

Thrust 1 – secondary: Sanjel, S., Colee, J., Barocco, R., Dufault, N.S., Tillman, B., Punja, Z. K., Seepaul, R., & Small, I.M. 2023. "Environmental factors influencing stem rot development in peanut: predictors and action thresholds for disease management". Phytopathology 114 (2) 393-404. https://doi.org/10.1094/PHYTO-05-23-0164-R

Thrust 1 – secondary: Sanjel, S., Guerra, V., Seepaul, R., Mackowiak, C., Punja, Z.K., Dufault, N.S., Tillman, B., Bradford, K.J., & Small, I.M. 2023. "Application of hydrothermal time models to predict sclerotial germination of Athelia rolfi". Phytopathology 114 (1) 126-136 https://doi.org/10.1094/PHYTO-04-23-0132-R

Thrust 3 ***(associated)***

Thrust 2 – secondary: Hawkins, E.M., Buckmaster, D.R. "Improving Yield Data Analysis Using Contextual Data". *Applied Engineering in Agriculture*. 2023 39(4):391-398. doi: 10.13031/aea.14655. https://elibrary.asabe.org/abstract.asp?aid=54393.

Thrust 1 – secondary: Toledo, C.A., Crawford, M. "Deep Learning Models Using Multi-Modal Remote Sensing for Prediction of Maize Yield in Plant Breeding Experiments". *IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium*, Pasadena, CA, USA, 2023, pp. 487-490, doi: 10.1109/IGARSS52108.2023.10281741. https://ieeexplore.ieee.org/abstract/document/10281741

APPENDIX IX. DATA MANAGEMENT PLAN

Dissemination of products of the research

Results of this project will be made public through a variety of means, including publication in scientific journals, written or oral presentation at scientific meetings, postings on the IoT4Ag web site and social media (LinkedIn, X (formerly Twitter), Facebook and Instagram), personal conversations with colleagues during conferences, seminar visits, and through educational materials. We will post publications, datasets, and algorithms on freely available websites as allowed by policies set by journal publishers, and/or as mandated by agency rules.

Expected data

The data expected to be generated during the course of this collaborative project will largely be digital in nature concerning the characterization of agricultural systems; the fabrication, characterization and performance of physical systems (sensors, communication and energy devices, aerial- and ground-based drones); and the creation of cyber-physical systems (data, algorithms, models, software). Common data file types that will be produced through the research and educational activities include:

- written reports and presentations (primarily *.doc, *.pdf, *.tex, *.ppt)
- digital images (primarily *.jpeg, .*tif, *.png, and *.gif)
- point clouds (LAS)
- schematic and layout files (*.DXF or *.DWG or *.GDSII format)
- any proprietary read-only data files from common scientific instruments (i.e., scanning electron microscopes, x-ray diffraction, atomic force microscope, UV-visible-NIR spectrometers, physical property measurement systems, electrochemical workstations etc.) will be converted to standard digital files along with data files (primarily *.txt, *xls, *.doc, etc.), supporting standard multi-column data sets analyzable in Microsoft Excel or Origin Pro software platforms.
- measurements of agricultural or physical systems will be produced in ASCII format; we note that other common scientific instruments which generate raw data, will also be saved in ASCII or .csv (comma separated value) formats whenever possible
- audio and video files (*.mpeg, *mp4, *.avi, etc.)
- data from some mobile platforms will be stored/shared using ROS bag files
- graph-based data in JavaScript Object Notation (JSON)
- socio-economic modeling (*.xls)
- code in Matlab, Python, R, Java, and C/C++

Creation of publicly available software

All code and software developed through the effort (including but not limited to code for simple simulations, data-fitted model design, and robotics calibration) will be made publicly available and posted on a public website. Whenever possible, software developed as part of this project will be published under the MIT Open Source License (or similar license), and hosted on a public code

repository, such as GitHub. Code to operate the vehicle testbed that utilizes the open-source Robot Operating System (ROS) and will be made available online, along with a bill of materials and assembly instructions for the hardware, so that other researchers will be able to recreate the testbed. Every code release (particularly any version discussed or referenced in publications) will be documented, posted and shared, and a DOI number will be obtained.

Creation of publicly available data sets

Simulations and field measurements will generate data sets. Appropriate data sets of this type will be made available in accepted formats. Processed data will be made available in standard CSV, JSON format, or other open standard where possible to enable maximum portability. Moreover, some raw image and video data will be made available to enable other researchers to process the data directly. All data sets will be paired with a datasheet to describe the collection mechanisms, their purpose and suggested use (e.g., as described by Gebru, et al., 2021, https://doi.org/10.1145/3458723)). Every data set release (particularly any set discussed or referenced in publications) will be documented, posted and shared, and a DOI number will be obtained.

A challenge, but one that will be addressed by this project, is to make the data accessible via API rather than always human-enabled download. Many of the data sets will: 1. Be too large to relay as CSV files, and 2. Have much more value in real-time than as "history". The real-time aspect would be for internal purposes initially, but the research and development toward IoT data accessible in real time is of real industry value. This will require publication of APIs with the data and continual attention toward standardizing those APIs with open source code. When sensors and models have reached a readiness level warranting outside evaluation, we will allow subscribers to access some data streams via NATS (using the Avena platform).

Any human subject data that is generated will be kept confidential and managed in a manner consistent with relevant institutional IRBs.

Data storage

Data will be stored at all IoT4Ag Universities in both shared user/field-testing facilities and in equipment/systems housed in the individual investigators' laboratories.

Data will also be stored in labs at our industrial and government partners. Data collected in shared user facilities and investigators labs will be stored on servers at the university of the individual investigator and subject to the individual university's data management policies. Data archiving is explained further below.

All presentations presented in IoT4Ag meetings will be archived on a secure IoT4Ag website and may be posted publicly when the data are sufficiently established and publication is planned. Presentations that are held virtually via Zoom or other web conference software will be recorded when appropriate and recordings will be stored on a protected on IoT4Ag site. Recorded presentations that are designed for public distribution will be stored and shared via YouTube.

Data standards

All participants in the research will review and, if necessary, update this plan, and confirm their mutual commitment to follow the protocols established here and maintain high standards in the management of data.

The produced data and metadata, descriptions of experiments, process details, raw materials, computational codes, computer calculations, and input conditions that are produced during the course of the research will be provided following the professional standards according to which they are produced. Elements of metadata include the following: identifiers for discovery and citation (*e.g.*, title, creator, subject); rights and access information; methodology, equipment, conditions and variables involved; file formats and file structures; versions, data processing and other indications of data modification; checksums and other data verification methods. If necessary, University of Pennsylvania library staff members will work with the PI to find existing metadata standards and to suggest additional metadata.

For true mining of insights, the data must have the full backstory or context (metadata) associated with it. At times, the definition of metadata and data gets blurred. For example, the speed of the planter might be "the data" to be interpreted if the decision and actions are control, path planning, or logistics of keeping the planter boxes filled; later, when trying to ascertain impacts of practices on production, speed of the planter would be metadata or context (as one of many variables which might have influenced yield). This project will deal with a very wide variety of data that could be collected in cropping systems (Table 1). Those data elements have assorted resolutions in both space and time, highly varied accuracy levels and different origination points (several machines or sensor systems); this offers a wild frontier of opportunity for improvement in the design of data collection, sharing, storage, transfer, and access systems as well as improvement in decisions and actions on actual farms. This is part of the novelty of this project and therefore data structure/access research becomes part of our agriculture and IoT research.

Table 1. Some typical data elements for cropping systems as well as examples of value.

Data Element	**Examples of Potential Value**
Records of who/what/where/when	Critical context for later analytics on production and logistics
Imagery (RGB, LiDAR, hyper-spectral, multi-spectral, thermal)	Scouting, anomaly detection, support analytics for treatment comparisons or correlation to other sensor data
Machine sensors (location, fuel consumption, battery status, slip, crop or soil moisture, speed, spray rate, seed rate)	Improved control of the machine functions, improved system logistics, metadata for analytics regarding practices

Soil sensors (moisture, temperature, chemical/biological attributes)	Improved logistics planning, influence on production activities, context for deeper analytics on other data

Archiving & preservation of access to data and other research products

During the term of the grant, data will be stored on university servers at each partner site. Stored data will be protected by disk mirroring and frequent backups, including off-site backups. Full-time system administrators monitor the security and availability of the systems. When feasible, data collected by IoT4Ag researchers at our industrial and government partner facilities will be archived at IoT4Ag headquarters. At the least, links to data stored elsewhere will be complete in a listing held at the University of Pennsylvania. All investigators will also be responsible for backing up raw and analyzed data to a centrally managed IoT4Ag server or cloud-based storage systems maintained by their own institutions. Data will be retained for at least three years after conclusion of the award or three years after public release, whichever is later. Exceptions requiring longer retention may occur when data supports patents or a larger library or collection useful to the broader community.

The missions of the University of Pennsylvania, Purdue University, University of California-Merced, and University of Florida, include the dissemination of the results of research by faculty, employees, students, and guest scholars for the purpose of adding to the body of knowledge and serving the public interest. The data generated under this project will be made available to others in several ways, including as digital files or printed documents. Data will be generally available for public release immediately after publication.

Penn's Institutional Data Repository, the Scholarly Commons (https://repository.upenn.edu/), will be used to disseminate pre-publication manuscripts, data, and metadata. The Scholarly Commons is a digital collection that captures and preserves Penn's intellectual output via web pages, on a server operated by the Penn Library. The main papers are all in PDF. Supported formats for data and metadata include JPEG, PNG, GIF, TIFF (images), AIFF, MP3, DRM-free AAC (audio), MPEG (video), XML and CSV (data). This is a permanent scholarly repository. The Library expects to preserve the content of the repository by migrating it to new technological platforms when and if the obsolescence of current technologies makes it necessary to do so. In this, the produced data will effectively be made available for a longer period than 3 years. In addition to electronically stored data, students and postdoctoral associates will be encouraged and required to keep detailed laboratory notebooks.

ERC researchers can disseminate IoT4Ag data through Scholarly Commons at Penn, but also may use their own institutional data repositories. For example, researchers at Purdue may use the Purdue University Research Repository (https://purr.purdue.edu/kb) in place of Scholarly

Commons. The Purdue University Research Repository digitally preserves data for public access with digital object identifiers and metadata and formatting oversight.

Policies and provisions for re-use, re-distribution, and the production of derivatives

The investigators will work with their technology transfer offices to transfer any inventions and innovative knowledge to outside organizations, as outlined in the Project Description. The technology transfer offices at each participating institution encourage invention disclosure, protect intellectual property, obtain and manage patents, copyrights and trademarks derived from academic research, and market and license intellectual property for commercialization.

Rights and obligations

The PI and site directors are responsible for the implementation of the Data Management Plan. If an investigator leaves a participating institution during or after the award, the dissemination of the research results for a minimum of three years after conclusion of the award or three years after public release, whichever is later, will be the responsibility of the PI or relevant site director.

Renewal

Our vision for data management in agriculture is that data needs to be interoperable regardless of the platform on which it is stored. Much data has value "in the moment" and only getting that data after the fact (sometimes after the season) is just too late. Through years 6-10, we anticipate building and exposing an infrastructure for data connections as a service. As the Meteorological Assimilation Data Ingest System (MADIS; https://madis.ncep.noaa.gov/) works with both NOAA and non-NOAA data providers to ingest, process, and distribute weather data, as described elsewhere, we will use the Neural Autonomic Transport System (NATS; https://nats.io/) to queue data on demand and by subscription.

The whole of ag data is huge and for big files (blob storage) such as hyperspectral imagery of large areas, we would serve the contextual metadata regarding time and location for these file packages. Smaller (atomic) sensor data will be a data stream via NATS. Examples would be soil moisture, machine location and speed, fuel consumption at a location, weather measurements, etc.

Packaging data in this innovative, interoperable, and scalable manner will require some archival storage if for nothing else than for demonstration and training purposes. Our hope is to build an ecosystem, as MADIS did, whereby agencies, institutions, and even for-profit firms leverage the raw data to provide data storage and access as well as services directly for insight and decision making. IoT4Ag is talking with data service companies to identify a partner to host Center data to be made publicly available and allow other research teams to develop and test their own AI-driven precision ag models.

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APPENDIX X: POSTDOC MENTORING PLAN

Postdoctoral researchers will be supported by **IoT4Ag**. All **IoT4Ag** postdoctoral researchers will have an **IoT4Ag** faculty investigator as a primary mentor, referred to as "the investigator" in the plan below.

1. Orientation will include in-depth conversations between the investigator and the Postdoctoral Researcher. Mutual expectations will be discussed and agreed upon in advance. Orientation topics will include (a) the amount of independence the Postdoctoral Researcher position requires, (b) interaction with coworkers, (c) productivity including the importance of scientific publications, (d) work habits, and (e) documentation of research methodologies and results so that the work can be continued by other researchers in the future. Furthermore, all postdocs will participate in the **IoT4Ag** boot camp.

2. Career Counseling will be directed at providing the Postdoctoral Researcher with the skills, knowledge, and experience needed to excel in his/her chosen career path. The Postdoctoral Researcher will be encouraged to discuss career options with any of the **IoT4Ag** faculty, researchers from member companies, and PhD-entrepreneurs at member start-ups. Furthermore, the Postdoctoral Researcher will be encouraged to take advantage of career counseling services on campus and workshops that are often available at academic conferences.

3. Experience with Preparation of Grant Proposals will be gained by direct involvement of the Postdoctoral Researcher in proposals prepared by the investigator. The Postdoctoral Researcher will have an opportunity to learn best practices in proposal preparation including identification of key research questions, definition of objectives, description of approach and rationale, and construction of a work plan, timeline, and budget.

4. Publications and Presentations are expected to result from the work supported by the center. These will be prepared under the direction of the investigator. The Postdoctoral Researcher will receive guidance and training in the preparation of manuscripts for scientific journals, presentations at conferences, and technical reports. **IoT4Ag** will also hold center-wide seminars on research paper writing and research presentations to provide postdoctoral researchers and students with formal training.

5. Teaching and Mentoring Skills will be developed in the context of regular meetings within **IoT4Ag** and the investigators' research group. In these meetings, undergraduate researchers, graduate students, postdoctoral researchers, and collaborators describe their work to colleagues within the group and assist each other with solutions to challenging research problems, often resulting in cross fertilization of ideas. Furthermore, the Postdoctoral Researcher will mentor undergraduate students and will have the opportunity to be a guest lecturer in formal engineering courses and **IoT4Ag** short courses, if desired.

6. Instruction in Professional Practices will be provided on a regular basis in the context of the research work and will include fundamentals of the scientific method, laboratory safety, and other standards of professional practice. In addition, the Postdoctoral Researcher will be encouraged to affiliate with one or more professional societies in his/her chosen field.

7. Technology Transfer is a central goal of the **IoT4Ag** ERC and thus postdoctoral researchers will be exposed to technology transfer through regular **IoT4Ag** innovation ecosystem activities**.** The Postdoctoral Researcher will be required to become familiar with the university-industry relationship including applicable confidentiality requirements and preparation of invention disclosure applications.

8. Success of the Mentoring Plan will be assessed by monitoring the personal progress of the Postdoctoral Researcher through tracking the Postdoctoral Researcher's progress toward his/her career goals after finishing the postdoctoral program.

APPENDIX XI. BIOGRAPHICAL SKETCHES

The biographical sketches of each member of the ERC faculty and leadership team begin on the next page in alphabetical order by last name.

IDENTIFYING INFORMATION:

NAME: Allen, Mark G

ORCID iD: https://orcid.org/0000-0003-3963-6359

POSITION TITLE: Alfred Filter Moore Professor and Chair of the Department of Electrical and Systems Engineering

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	Postdoctoral Fellow	05/1989 – 09/1989	Microelectronics
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	PHD	05/1989	Microelectronics/Chemical Engineering
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	MS	05/1986	Chemical Engineering
University of Pennsylvania, Philadelphia, Pennsylvania, United States	BENG	05/1988	Electrical Engineering
University of Pennsylvania, Philadelphia, Pennsylvania, United States	BENG	05/1984	Chemical Engineering
University of Pennsylvania, Philadelphia, Pennsylvania, United States	BA	05/1984	Chemistry

Appointments and Positions

2024 - present	Alfred Filter Moore Professor and Chair of the Department of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2013 - 2024	Alfred Filter Moore Professor and Director of the Singh Center for Nanotechnology, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2011 - 2013	Executive Director, Institute of Electronics and Nanotechnology, Georgia Institute of Technology, Atlanta, Georgia, United States
2007 - 2010	Senior Vice Provost for Research and Innovation, Georgia Institute of Technology, Atlanta, Georgia, United States
2005 - 2013	Regents' Professor, Georgia Institute of Technology, Electrical and Computer Engineering, Atlanta, Georgia, United States
2000 - 2013	Professor, Georgia Institute of Technology, Electrical and Computer Engineering, Atlanta, Georgia, United States
2000 - 2000	Visiting Professor, Swiss Federal Institute of Technology, Zurich, Not Applicable, N/A, Switzerland
1998 - 1998	Visiting Professor, Swiss Federal Institute of Technology, Zurich, Not Applicable, N/A, Switzerland

1994 - 1999	Associate Professor, Georgia Institute of Technology, Electrical and Computer Engineering, Atlanta, Georgia, United States
1994 - 1994	Visiting Professor, Swiss Federal Institute of Technology, Zurich, Not Applicable, N/A, Switzerland
1989 - 1994	Assistant Professor, Georgia Institute of Technology, Electrical Engineering, Atlanta, Georgia, United States

Products

Products Most Closely Related to the Proposed Project

1. Zhang J, Huang Y, Yang Q, Venkatesh V, Synodis M, Pikul JH, Bidstrup Allen SA, Allen MG. High-Energy-Density Zinc-Air Microbatteries with Lean PVA-KOH-K(2)CO(3) Gel Electrolytes. ACS Appl Mater Interfaces. 2023 Feb 8;15(5):6807-6816. PubMed PMID: 36700920.
2. Zhang T, Tsang M, Du L, Kim M, Allen MG. Electrical Interconnects Fabricated From Biodegradable Conductive Polymer Composites. IEEE Trans Compon Packaging Manuf Technol. 2019 May;9(5):822-829. PubMed Central PMCID: PMC6553660.
3. Venkatesh V, Yang Q, Zhang J, Huang Y, Pikul J, Allen S, Allen M. Zinc film anodes for air microbatteries: fabrication, approaches, and utilization optimization. Journal of Micromechanics and Microengineering. 2023 March 13; 33(5):055001-. Available from: https://iopscience.iop.org/article/10.1088/1361-6439/acbc2d DOI: 10.1088/1361-6439/acbc2d
4. Huang, Y., Zhang, J., Yang, Q., Venkatesh, V., Pikul, J.H., Allen, M.G. and Allen, S.A.B. Mechanistic Study of Hydroxide Ion Consumption in Ultralean PVA Hydrogel Electrolytes for High-Energy-Density Micro Zinc-Air Batteries. Journal of The Electrochemical Society. 2023 October.
5. Luo M, Martinez A, Song C, Herrault F, Allen M. A Microfabricated Wireless RF Pressure Sensor Made Completely of Biodegradable Materials. Journal of Microelectromechanical Systems. 2014 February; 23(1):4-13. Available from: http://ieeexplore.ieee.org/document/6675016/ DOI: 10.1109/JMEMS.2013.2290111

Other Significant Products, Whether or Not Related to the Proposed Project

1. Mahmoodi SR, Xie P, Zachs DP, Peterson EJ, Graham RS, Kaiser CRW, Lim HH, Allen MG, Javanmard M. Single-step label-free nanowell immunoassay accurately quantifies serum stress hormones within minutes. Sci Adv. 2021 Jun;7(27) PubMed Central PMCID: PMC8245048.
2. Choi SO, Kim YC, Lee JW, Park JH, Prausnitz MR, Allen MG. Intracellular protein delivery and gene transfection by electroporation using a microneedle electrode array. Small. 2012 Apr 10;8(7):1081-91. PubMed Central PMCID: PMC3516926.
3. Vitale F, Shen W, Driscoll N, Burrell JC, Richardson AG, Adewole O, Murphy B, Ananthakrishnan A, Oh H, Wang T, Lucas TH, Cullen DK, Allen MG, Litt B. Biomimetic extracellular matrix coatings improve the chronic biocompatibility of microfabricated subdural microelectrode arrays. PLoS One. 2018;13(11):e0206137. PubMed Central PMCID: PMC6211660.
4. Klosterhoff BS, Tsang M, She D, Ong KG, Allen MG, Willett NJ, Guldberg RE. Implantable Sensors for Regenerative Medicine. J Biomech Eng. 2017 Feb 1;139(2):0210091-02100911.

PubMed Central PMCID: PMC5253675.

5. She D, Allen M. A Self-Powered, Biodegradable Dissolved Oxygen Microsensor. Journal of Microelectromechanical Systems. 2020 October; 29(5):1074–1078. Available from: https://ieeexplore.ieee.org/document/9195501/ DOI: 10.1109/JMEMS.2020.3013208

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729–3733 and 3802.

Certified by Allen, Mark G in SciENcv on 2024-07-18 16:49:38

Name: Mark Allen
ORCID iD:
Position Title: Professor
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. Director, Mid-Atlantic Nanotechnology Hub (MANTH) of the NSF Nanotechnology Coordinated Infrastructure (NNCI) Program. (MANTH is comprised of the University of Pennsylvania and the Community College of Philadelphia.)
2. Editorial Board Member, Microsystems and Nanoengineering (Nature Publishing Group)
3. Fellow, Institute of Electrical and Electronics Engineers (IEEE)
4. Member, National Academy of Engineering

IDENTIFYING INFORMATION:

NAME: Arnold, David

ORCID iD: https://orcid.org/0000-0003-2515-7218

POSITION TITLE: George Kirkland Engineering Leadership Professor

PRIMARY ORGANIZATION AND LOCATION: Unviersity of Florida, Department of Electrical and Computer Engineering, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Georgia Tech, Atlanta, Georgia, United States	Postdoctoral Fellow	12/2005	Micro/nano Engineering
Georgia Tech, Atlanta, Georgia, United States	PHD	12/2004	Electrical & Computer Engineering
University of Florida, Gainesville, Florida, United States	MS	12/2001	Electrical & Computer Engineering
University of Florida, Gainesville, Florida, United States	BS	12/1999	Electrical Engineering
University of Florida, Gainesville, Florida, United States	BS	12/1999	Computer Engineering

Appointments and Positions

2016 - present	George Kirkland Engineering Leadership Professor, Unviersity of Florida, Department of Electrical and Computer Engineering, Gainesville, Florida, United States
2014 - 2016	Professor, University of Florida, Electrical & Computer Engineering, Gainesville, Florida, United States
2012 - 2013	Interim Director, University of Florida, F Nanoscience Institute for Medical and Engineering Technology, Gainesville, Florida, United States
2010 - 2020	Affiliate Professor, University of Florida, Materials Science & Engineering, Gainesville, Florida, United States
2010 - 2014	Associate Professor, University of Florida, Electrical & Computer Engineering, Gainesville, Florida, United States
2005 - 2010	Assistant Professor, University of Florida, Electrical & Computer Engineering, Gainesville, Florida, United States

Products

Products Most Closely Related to the Proposed Project

1. Challa VR, Mur-Miranda JO, Arnold DP. Wireless power transmission to an electromechanical receiver using low-frequency magnetic fields,". Smart Mater. Struct. 2012 November; 21(11).
2. Crasto V, Stormant M, Arnold D. Electrodynamic Wireless Power Transfer to High-Performance Rotating Magnet Receivers. 2023 IEEE 22nd International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications

(PowerMEMS). 2023 IEEE 22nd International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS); ; Abu Dhabi, United Arab Emirates. IEEE; c2023. Available from: https://ieeexplore.ieee.org/document/10417617/ DOI: 10.1109/PowerMEMS59329.2023.10417617

3. Crasto V, Stormant M, Arnold D. A Three-Phase Rotating Magnet Electrodynamic Wireless Power Transmission Receiver. 2023 IEEE SENSORS. 2023 IEEE SENSORS; ; Vienna, Austria. IEEE; c2023. Available from: https://ieeexplore.ieee.org/document/10324860/ DOI: 10.1109/SENSORS56945.2023.10324860
4. Halim M, Rendon-Hernandez A, Smith S, Arnold D. Analysis of a Dual-Transduction Receiver for Electrodynamic Wireless Power Transfer. IEEE Transactions on Power Electronics. 2022; 37(6):7470-7479. Available from: https://ieeexplore.ieee.org/document/9672672/ DOI: 10.1109/TPEL.2022.3140777
5. Kagan C, Arnold D, Cappelleri D, Keske C, Turner K. Special report: The Internet of Things for Precision Agriculture (IoT4Ag). Computers and Electronics in Agriculture. 2022 May; 196:106742-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S016816992200059X DOI: 10.1016/j.compag.2022.106742

Other Significant Products, Whether or Not Related to the Proposed Project

1. Arnold DP, Cheng S, Challa VR., inventors. Wireless Power Transfer via Electrodynamic Coupling,. US 10,541,558. 2020 January 21.
2. Wang Y. Ultra-thick electroplated CoPt magnets for MEMS. J. Microelectromech. Syst.. 2019 April; 28(2):311-320.
3. Arnold DP, Garraud A, Garraud N., inventors. Wireless Power Transfer Using One or More Rotating Magnets in a Receiver. US 10,218,221. 2019 February 26.
4. Arnold DP, Cheng S, Challa VR., inventors. 10,541,558. US 9,866,066,. 2018 January 09.

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Arnold, David in SciENcv on 2024-06-21 12:23:01

Name: Arnold, David P.
ORCID iD: 0000-0003-2515-7218
Position Title: George Kirkland Engineering Leadership Professor
Primary Organization and Location: University of Florida, Gainesville, FL

Synergistic Activities:

1. Broadening Participation of Women in Engineering – mentored four female PhD graduates, three female postdoc, and many female undergraduate research students
2. Broadening Participation of Underrepresented Minorities in Engineering – graduated two Hispanic PhD doctoral students; ongoing mentorship of African-American and Hispanic REU students
3. Editorial Boards: J. Micromechanics and Microengineering, Micromachines
4. Conference Technical Program Committees (last 3 years): 2024 PowerMEMS, 2023 PowerMEMS, 2022 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), 2022 PowerMEMS, 2022 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), 2021 IEEE Wireless Power Transfer Conf., 2021 IEEE Intermag,
5. Director of Florida Semiconductor Institute

IDENTIFYING INFORMATION:

NAME: Arratia, Paulo

ORCID iD: https://orcid.org/0000-0002-2566-2663

POSITION TITLE: Professor of Mechanical Engineering & Applied Mechanics

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Pennsylvania, Philadelphia, Pennsylvania, United States	Postdoctoral Fellow	10/2005 - 06/2007	Physics & Astronomy
Haverford College, Haverford , Pennsylvania, United States	Postdoctoral Fellow	06/2003 - 09/2005	Physics & Astronomy
Rutgers University, New Brunswick, New Jersey, United States	PHD	05/2003	Chemical & Biochemical Engineering
Rutgers University, New Brunswick, NJ, USA	PHD	05/2003	Chemical & Biochemical Engineering
Hampton University, Hampton, Virginia, United States	BS	05/1997	Chemical Engineering

Appointments and Positions

2017 - present	Professor of Mechanical Engineering & Applied Mechanics, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2023 - 2023	Visiting Professor, University of Saarland, Dept. Physics, Saarbrucken, Not Applicable, N/A, Germany
2023 - 2023	Visiting Scholar, University of Edinburgh, Edinburgh, Not Applicable, N/A, United Kingdom
2020 - 2020	Visiting Professor, University of Paris, Dept. of Physics, Paris, Not Applicable, N/A, France
2012 - 2017	Associate Professor of Mechanical Engineering & Applied Mechanics, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2007 - 2012	Assistant Professor of Mechanical Engineering & Applied Mechanics, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Products

Products Most Closely Related to the Proposed Project

1. Kostynick R, Matinpour H, Pradeep S, Haber S, Sauret A, Meiburg E, Dunne T, Arratia P, Jerolmack D. Rheology of debris flow materials is controlled by the distance from jamming. Proc Natl Acad Sci U S A. 2022 Nov;119(44):e2209109119. PubMed Central PMCID: PMC9636957.

2. Galloway KL, Ma X, Keim NC, Jerolmack DJ, Yodh AG, Arratia PE. Scaling of relaxation and excess entropy in plastically deformed amorphous solids. Proc Natl Acad Sci U S A. 2020 Jun 2;117(22):11887-11893. PubMed Central PMCID: PMC7275772.
3. Graham IR, Arratia PE, Riggleman RA. Exploring the relationship between softness and excess entropy in glass-forming systems. J Chem Phys. 2023 May 28;158(20) PubMed PMID: 37218701.
4. Galloway KL, Teich E, Ma X, Kammer C, Graham I, Keim N, Reina C, Jerolmack D, Yodh A, Arratia PE. Relationships between structure, memory and flow in sheared disordered materials. Nature Physics. 2022 March; 18:565-570. DOI: 10.1038/s41567-022-01536-9
5. Deshpande NS, Furbish DJ, Arratia PE, Jerolmack DJ. The perpetual fragility of creeping hillslopes. Nat Commun. 2021 Jun 23;12(1):3909. PubMed Central PMCID: PMC8222271.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Qin B, Arratia PE. Confinement, chaotic transport, and trapping of active swimmers in time-periodic flows. Sci Adv. 2022 Dec 9;8(49):eadd6196. PubMed Central PMCID: PMC9728977.
2. Cubuk ED, Ivancic RJS, Schoenholz SS, Strickland DJ, Basu A, Davidson ZS, Fontaine J, Hor JL, Huang YR, Jiang Y, Keim NC, Koshigan KD, Lefever JA, Liu T, Ma XG, Magagnosc DJ, Morrow E, Ortiz CP, Rieser JM, Shavit A, Still T, Xu Y, Zhang Y, Nordstrom KN, Arratia PE, Carpick RW, Durian DJ, Fakhraai Z, Jerolmack DJ, Lee D, Li J, Riggleman R, Turner KT, Yodh AG, Gianola DS, Liu AJ. Structure-property relationships from universal signatures of plasticity in disordered solids. Science. 2017 Nov 24;358(6366):1033–1037. PubMed Central PMCID: PMC6047528.
3. Keim NC, Arratia PE. Mechanical and microscopic properties of the reversible plastic regime in a 2D jammed material. Phys Rev Lett. 2014 Jan 17;112(2):028302. PubMed PMID: 24484046.
4. Teich EG, Galloway KL, Arratia PE, Bassett DS. Crystalline shielding mitigates structural rearrangement and localizes memory in jammed systems under oscillatory shear. Sci Adv. 2021 May;7(20) PubMed Central PMCID: PMC8115929.
5. Arratia PE. Life in Complex Fluids: Swimming in Polymers. Physical Review Fluids. 2022 November 21; 7:110515. Available from: https://doi.org/10.1103/PhysRevFluids.7.110515

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Certified by Arratia, Paulo in SciENcv on 2024-07-16 13:17:26

Name: Paulo Arratia

ORCID iD:
Position Title: Professor
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. Training: The PI has mentored many graduated students from diverse backgrounds who have gone on to industry and academia.
2. Curriculum development: The PI has developed a new engineering curriculum that promotes active learning & hands-on activities for undergraduate students.
3. Contributions to the Science of Learning: The PI has created and shared (with other institutions) demos that illustrate key concepts of fluid dynamics, rheology, and soft matter.
4. Broadening the Participation of Groups Underrepresented in STEM: The PI serves as the Co-Lead for Diversity, Equity & Inclusion (DCI) thrust of an NSF ERC IoT4Ag focused on developing events and programs across several institutions including a Path to PhD Program for undergraduate students.

IDENTIFYING INFORMATION:

NAME: Bidstrup Allen, Sue Ann

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: Chemical & Biomolecular Engineering Department, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Minnesota, Minneapolis, Minnesota, United States	PHD	05/1986	Chemical Engineering
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	Bachelor of Engineering (SB)	05/1981	Chemical Engineering

Appointments and Positions

2014 - present	Professor, Chemical & Biomolecular Engineering Department, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2015 - 2024	Associate Dean , School of Engineering and Applied Science, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2011 - 2014	Associate Dean, College of Engineering, Georgia Institute of Technology, Atlanta, Georgia, United States
2009 - 2011	Associate Chair, School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, Atlanta, Georgia, United States
2005 - 2009	Faculty Executive Assistant to the President, Office of the President, Georgia Institute of Technology, Atlanta, Georgia, United States
2000 - 2014	Professor, School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, Atlanta, Georgia, United States
1994 - 2000	Associate Professor, School of Chemical & Biomolecular Engineering, Atlanta, Georgia, United States
1988 - 1994	Assistant Professor, School of Chemical & Biomolecular Engineering, Georgia Institute of Technology, Atlanta, Georgia, United States
1986 - 1988	Postdoctoral Associate, Electrical Engineering Dept., Massachusetts Institute of Technology, Cambridge, Massachusetts, United States

Products

Products Most Closely Related to the Proposed Project

1. Zhang J, Huang Y, Yang Q, Venkatesh V, Synodis M, Pikul JH, Bidstrup Allen SA, Allen MG. High-Energy-Density Zinc–Air Microbatteries with Lean PVA-KOH-K(2)CO(3) Gel Electrolytes. ACS Appl Mater Interfaces. 2023 Feb 8;15(5):6807-6816. PubMed PMID: 36700920.
2. Huang Y, Zhang J, Yang Q, Venkatesh V, Pikul J, Allen M, Allen S. Mechanistic Study of Hydroxide Ion Consumption in Ultralean PVA Hydrogel Electrolytes for High-Energy-Density

Micro Zinc–Air Batteries. Journal of The Electrochemical Society. 2023 October 20; 170(10):100523-. Available from: https://iopscience.iop.org/article/10.1149/1945-7111/ad02c0 DOI: 10.1149/1945-7111/ad02c0

3. Venkatesh V, Yang Q, Zhang J, Huang Y, Pikul J, Allen S, Allen M. Zinc film anodes for air microbatteries: fabrication, approaches, and utilization optimization. Journal of Micromechanics and Microengineering. 2023 March 13; 33(5):055001-. Available from: https://iopscience.iop.org/article/10.1088/1361-6439/acbc2d DOI: 10.1088/1361-6439/acbc2d
4. Zhang J, Huang Y, Yang Q, Venkatesh V, Synodis M, Pikul J, Bidstrup Allen S, Allen M. High-Energy-Density Zinc–Air Microbatteries with Lean PVA–KOH–K_2CO_3 Gel Electrolytes. ACS Applied Materials & Interfaces. 2023 January 26; 15(5):6807-6816. Available from: https://pubs.acs.org/doi/10.1021/acsami.2c19970 DOI: 10.1021/acsami.2c19970
5. Huang Y, Vyletel J, Allen M, Ann Bidstrup Allen S. Microfabrication-Enhanced Carbon Fiber Cathodes for High Discharge Rate Aluminum-Air Batteries. 2022 21st International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS). 2022 21st International Conference on Micro and Nanotechnology for Power Generation and Energy Conversion Applications (PowerMEMS); ; Salt Lake City, UT, USA. IEEE; c2022. Available from: https://ieeexplore.ieee.org/document/10007619/ DOI: 10.1109/PowerMEMS56853.2022.10007619

Other Significant Products, Whether or Not Related to the Proposed Project

1. Synodis M, Pikul J, Ann Bidstrup Allen S, Allen M. Vertically integrated high voltage Zn-Air batteries enabled by stacked multilayer electrodeposition. Journal of Power Sources. 2020 February; 449:227566-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0378775319315599 DOI: 10.1016/j.jpowsour.2019.227566
2. Synodis M, Kim M, Allen M, Allen S. 3D lithium ion battery fabrication via scalable stacked multilayer electrodeposition. Journal of Micromechanics and Microengineering. 2019 May 01; 29(5):055006-. Available from: https://iopscience.iop.org/article/10.1088/1361-6439/ab0c60 DOI: 10.1088/1361-6439/ab0c60
3. Huang C, Armutlulu A, Allen M, Allen S. Model-assisted development of microfabricated 3D Ni(OH) 2 electrodes with rapid charging capabilities. Journal of Power Sources. 2017 August; 358:101-111. Available from: https://linkinghub.elsevier.com/retrieve/pii/S037877531730650X DOI: 10.1016/j.jpowsour.2017.05.017
4. Tsang M, Armutlulu A, Martinez A, Allen S, Allen M. Biodegradable magnesium/iron batteries with polycaprolactone encapsulation: A microfabricated power source for transient implantable devices. Microsystems & Nanoengineering. 2015 October 12; 1(1):-. Available from: https://www.nature.com/articles/micronano201524 DOI: 10.1038/micronano.2015.24
5. Tsang M, Armutlulu A, Herrault F, Shafer R, Allen S, Allen M. Development of Electroplated Magnesium Microstructures for Biodegradable Devices and Energy Sources. Journal of Microelectromechanical Systems. 2014 December; 23(6):1281-1289. Available from: http://ieeexplore.ieee.org/document/6919999/ DOI: 10.1109/JMEMS.2014.2360201

Certification:

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Certified by Bidstrup Allen, Sue Ann in SciENcv on 2024-07-12 11:08:00

Name: Sue Ann Bidstrup Allen
ORCID iD:
Position Title: Professor
Primary Organization and Location: University of Pennsylvania, Philadelphia, PA

Synergistic Activities:

1. Commissioner of the ABET Engineering Accreditation Board
2. Vice-Chair of the American Institute of Chemical Engineering Education and Accreditation Committee
3. Recipient of the 2008 American Society of Engineering Education Sharon Keillor Award for Women in Education and the 2008 Council of Chemical Research Diversity Award
4. Faculty Advisor for the A. James Clark Scholars Program for first generation and highly aided university students
5. Faculty Director of the SUNFEST Research Experience for Undergraduate Programs (2019-2024)

IDENTIFYING INFORMATION:

NAME: Boyce, Ayesha

ORCID iD: https://orcid.org/0000-0002-9509-8703

POSITION TITLE: Associate Professor

PRIMARY ORGANIZATION AND LOCATION: Arizona State University , Division of Educational Leadership and Innovation, Tempe, Arizona, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Illinois at Urbana-Champaign, Champaign, Illinois, United States	PHD	12/2014	Educational Psychology - Evaluation Specialization
California State University Long Beach, Long Beach, California, United States	MA	08/2009	Research Psychology
Arizona State University, Tempe, Arizona, United States	BS	05/2005	Psychology

Appointments and Positions

2021 - present Associate Professor, Arizona State University , Division of Educational Leadership and Innovation, Tempe, Arizona, United States

2023 - present Board Member-at-Large, American Evaluation Association , Washington, District of Columbia, United States

2021 - present Affiliate Faculty, Center for Culturally Responsive Evaluation and Assessment, Urbana, Illinois, United States

2019 - present Co-Director, STEM Program Evaluation Lab, Tempe, Arizona, United States

2019 - 2021 Co-Director, UNCG Office of Assessment, Evaluation, and Research Services, Greensboro, North Carolina, United States

2015 - 2021 Assistant Professor, UNC Greensboro, Department of Educational Research Methodology, Greensboro , North Carolina, United States

2014 - 2015 Post-Doctoral Researcher, University of Illinois at Urbana-Champaign, I-STEM Education Initiative, Champaign, Illinois, United States

Products

Products Most Closely Related to the Proposed Project

1. Reid A, Boyce A, Chuquiruna J, Somo-Aina O, Malloy C, Stephenson S. A values-engaged, educative training model for novice evaluators. New Directions for Evaluation. 2023 May 25; 2023(177):135-143. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ev.20544 DOI: 10.1002/ev.20544
2. Boyce A, Reid A, Avent C, Adetogun A, Moller J, Singletary B. Social Justice as Ontology: The Intersection of Black Evaluators' Identities, Roles, and Practice. American Journal of

Evaluation. 2022 December 20; 44(3):528-548. Available from: http://journals.sagepub.com/doi/10.1177/10982140221108664 DOI: 10.1177/10982140221108664

3. Boyce A, Tovey T, Onwuka O, Moller J, Clark T, Smith A. Exploring NSF-Funded Evaluators' and Principal Investigators' Definitions and Measurement of Diversity, Equity, and Inclusion. American Journal of Evaluation. 2022 November 30; 44(1):50-73. Available from: http://journals.sagepub.com/doi/10.1177/10982140221108662 DOI: 10.1177/10982140221108662
4. Boyce A. Lessons learned using a values-engaged approach to attend to culture, diversity, and equity in a STEM program evaluation. Evaluation and Program Planning. 2017 October; 64:33-43. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0149718916301987 DOI: 10.1016/j.evalprogplan.2017.05.018
5. Boyce A, Chouinard J. Moving Beyond the Buzzword: A Framework for Teaching Culturally Responsive Approaches to Evaluation. Canadian Journal of Program Evaluation. 2017 December 04; 32(2):-. Available from: https://journalhosting.ucalgary.ca/index.php/cjpe/article/view/31132 DOI: 10.3138/10.3138/cjpe.31132

Other Significant Products, Whether or Not Related to the Proposed Project

1. Henderson J, Hines E, Boyce A, Golden M, Singleton II P, Davis J, Slack T, Junqueira W. FACTORS IMPACTING ENGINEERING ADVANCED DEGREE PURSUIT AND ATTAINMENT AMONG BLACK MALES. Journal of Women and Minorities in Science and Engineering. 2022; 28(4):1-24. Available from: http://www.dl.begellhouse.com/journals/00551c876cc2f027,3b6558aa06dbcd92,6a19983e5704b DOI: 10.1615/JWomenMinorScienEng.2021036005
2. Strategies for Mentoring and Advising Evaluation Graduate Students of Color. The Canadian Journal of Program Evaluation. 2021 March. Available from: https://journalhosting.ucalgary.ca/index.php/cjpe/article/view/69574
3. Orozco G.A., Avent C.M., Reid A., Boyce A., Taylor D.K.. Continuing to Nurture Undergraduates in STEM: Evaluation of a Polymer-infused Chemistry Research Experience for Undergraduates at an HBCU. Journal of Negro Education. 2021; 90(3):411-423. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-85138597554&partnerID=MN8TOARS eid: 2-s2.0-85138597554
4. Reid A, Boyce A, Adetogun A, Moller J, Avent C. If Not Us, Then Who? Evaluators of Color and Social Change. New Directions for Evaluation. 2020 July 10; 2020(166):23-36. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ev.20407 DOI: 10.1002/ev.20407
5. Boyce A, Avent C, Adetogun A, Servance L, DeStefano L, Nerem R, Platt M. Implementation and evaluation of a biotechnology research experience for African-American high school students. Evaluation and Program Planning. 2019 February; 72:162-169. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0149718917303452 DOI: 10.1016/j.evalprogplan.2018.10.004

Certification:

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Certified by Boyce, Ayesha in SciENcv on 2024-06-26 20:01:23

Synergistic Activities; Ayesha Boyce

1. External Evaluation of National Science Foundation IMOD STC, 2021-present
2. External Evaluation of BIMS/Hampton Univ National Science Foundation Racial Equity Project, 2023-present
3. Co-PI National Science Foundation EvaluATE (DEI Research Lead), 2018-present
4. External Evaluation of Department of Defense, Scalable Asymmetric Lifecycle Engagement (SCALE) 2023-present
5. External Evaluation of STEM PUSH NSF INCLUDES Alliance, 2019 – 2024

IDENTIFYING INFORMATION:

NAME: Brier, Robert A.

POSITION TITLE: IoT4Ag Managing Director

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Boston University, Boston, Massachusetts, United States	MPH	05/1994	Social and Behavioral Communications
Connecticut College, New London, Connecticut, United States	BA	05/1989	Psychology

Appointments and Positions

2023 - present	IoT4Ag Managing Director, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2021 - 2023	Administrative Director, Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, United States
2020 - 2021	IoT4Ag Administrative Director, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2018 - 2020	Director of Strategic Affairs / CBBG Administrative Director, University of Arizona, Tempe, Arizona, United States
2016 - 2017	Senior Financial and Administrative Officer, National Academies of Science, Washington, District of Columbia, United States
2011 - 2016	Director of Finance and Administration, Brookings Institution, Washington, District of Columbia, United States
2010 - 2011	Director of Grants Services, Georgetown University, Washington, District of Columbia, United States
2008 - 2010	Department Administrator, Dana-Farber Cancer Institute, Boston, Massachusetts, United States
2002 - 2008	Associate / Director of Administration, Harvard School of Public Health, Boston, Massachusetts, United States

Products

Products Most Closely Related to the Proposed Project

Other Significant Products, Whether or Not Related to the Proposed Project

Certification:

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Certified by Brier, Robert A. in SciENcv on 2024-06-05 18:00:52

Synergistic Activities

Robert (Bob) Brier
Administrative Director
University of Pennsylvania

N/A

IDENTIFYING INFORMATION:

NAME: Buckmaster, Dennis

ORCID iD: https://orcid.org/0000-0002-5586-141X

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Michigan State University, East Lansing, Michigan, United States	PHD	08/1989	Agricultural Engineering
Michigan State University, East Lansing, Michigan, United States	MS	05/1986	Agricultural Engineering
Purdue University, West Lafayette, IN, United States	BS	05/1984	Agricultural Engineering

Appointments and Positions

2006 - present	Professor, Purdue University, West Lafayette, Indiana, United States
2014 - 2024	Professor and Dean's Fellow for Digital Agriculture, Purdue University, West Lafayette, IN, United States
2014 - 2018	Assistant Dean, Purdue University, West Lafayette, IN, United States
2006 - 2013	Associate Professor, Purdue University, West Lafayette, IN, United States
1994 - 2006	Associate Professor, Penn State University, University Park, PA, United States
1989 - 1994	Assistant Professor, Penn State University, University Park, PA, United States

Products

Products Most Closely Related to the Proposed Project

1. Witkowski N, Buckmaster D, Basir MS, Sakata H. Facilitating Digital Agriculture with Simple Databases. Journal of the National Association of County Agricultural Agents. 2024 June; 17(1). Available from: https://www.nacaa.com/journal/5250c03c-9fc8-4a2e-afd2-3dcb2c572cca
2. Hundal GS, Laux CM, Buckmaster D, Sutton M, Langemeier M. Exploring the Barriers to the Adoption of Internet of Things-Based Precision Agriculture Practices. Agriculture. 2023 September; 13(1):163. Available from: https://www.mdpi.com/2077-0472/13/1/163
3. Basir MS, Noel S, Buckmaster D, Ashik-E-Rabbani M. Enhancing Subsurface Soil Moisture Forecasting: A Long Short-Term Memory Network Model Using Weather Data. Agriculture. 2024 February; 14(3):333. Available from: https://www.mdpi.com/2077-0472/14/3/333
4. Zhang Y, Love DJ, Krogmeier JV, Andersen CR, Heath RW, Buckmaster DR. Challenges and opportunities of future rural wireless communications. IEEE Communications Magazine. 2021; 59(12):16. Available from: https://ieeexplore.ieee.org/abstract/document/9681630
5. Hawkins EM, Buckmaster DR. Improving Yield Data Analysis Using Contextual Data. Applied Engineering in Agriculture. Applied Engineering in Agriculture. 2023; 9(4):391. Available

from: https://elibrary.asabe.org/abstract.asp?aid=54393

Other Significant Products, Whether or Not Related to the Proposed Project

1. Noel SA, Ault AC, Buckmaster DR, Krogmeier JV. A Rainfall-Based, Sequential Depression–Filling Algorithm and Assessments on a Watershed in Northeastern Indiana, USA. Journal of Advances in Modeling Earth Systems. 2021; 13(6). Available from: https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020MS002362
2. Layton A, Krogmeier JV, Ault A, Buckmaster DR. From yield history to productivity zone identification with hidden Markov random fields. Precision Agriculture. 2020; 21:762. Available from: https://link.springer.com/article/10.1007/s11119-019-09694-2
3. Chaterji S, Delay N, Evans J, Mosier N, Engel B, Buckmaster D, Ladisch M, Chandra R. LATTICE: Machine Learning, Data Engineering, and Policy Considerations for Digital Agriculture at Scale. IEEE Internet of Things Journal. 2020. Available from: https://hal.science/hal-03096467
4. Wang Y, Zhang Y, Buckmaster D, Krogmeier J. A Methodology for Combine Performance Analyses in Wheat Harvests with GNSS Data. Journal of the ASABE. 2023; 66(6):1391. Available from: https://elibrary.asabe.org/abstract.asp?aid=54453&t=2&redir=&redirType=
5. Wang Y, Liu H, Krogmeier J, Reibman A, Buckmaster D. ISOBlue HD: An Open-Source Platform for Collecting Context-Rich Agricultural Machinery Datasets. Sensors (Basel). 2020 Oct 12;20(20) PubMed Central PMCID: PMC7600794.

Certification:

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Certified by Buckmaster, Dennis in SciENcv on 2024-07-02 14:15:02

Synergistic Activities

Buckmaster, Dennis
Purdue University
Agricultural & Biological Engineering

Synergistic Activities

1. Thrust-3 (agricultural response systems) co-lead of NSF IoT4Ag Engineering Research Center in collaboration with university of Pennsylvania, University of Florida, University of California-Merced, and University of Arizona.
2. Co-lead of the Open Ag Technology and Systems Center bringing open-source technologies to agriculture with strong emphasis on graduate training
3. As Deans Fellow for Digital Agriculture, coordinate and administer programs related to connectivity, sensors, data architecture, analytics, and decision tools for agriculture including production, processing, and logistics
4. Active Extension and Outreach program related to private databases and introduction to data analytics for farmers and other agriculturalists.
5. Instructor for Ag Tech and Innovation course as part of the Explorations in AI for Agriculture learning community and Computing Technology with Applications course that contributes to a Data Driven Agriculture minor and a Certificate in Applications of Data Science.

IDENTIFYING INFORMATION:

NAME: Cappelleri, David

ORCID iD: https://orcid.org/0000-0001-7222-0625

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: Purdue University, School of Mechanical Engineering, West Lafayette, IN, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Pennsylvania, Philadelphia, PA, USA	Postdoctoral Fellow	09/2008 - 11/2008	Mechanial Engineering & Applied Mechanics
University of Pennsylvania, Philadelphia, PA, USA	PHD	08/2008	Mechanical Engineering & Applied Mechanics
The Pennsylvania State University, State College, PA, USA	MS	05/2000	Mechanical Engineering
Villanova University, Villanova, PA, USA	BS	05/1998	Mechanical Engineering

Appointments and Positions

2022 - present Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN, United States

2024 - present Assistant Vice President for Research Innovation, Purdue University, West Lafayette, Indiana, United States

2022 - present Member, Purdue Institute for Cancer Research, West Lafayette, IN, United States

2022 - present Professor, Purdue University, Weldon School of Biomedical Engineering (By Courtesy), West Lafayette, IN, USA

2021 - 2022 Associate Professor, Purdue University, Weldon School of Biomedical Engineering (By Courtesy), West Lafayette, IN, USA

2017 - 2022 Associate Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN, United States

2013 - 2017 Assistant Professor, Purdue University, School of Mechanical Engineering, West Lafayette, IN, USA

2009 - 2013 Assistant Professor, Stevens Institute of Technology, Department of Mechanical Engineering, Hoboken, NJ, USA

2002 - 2003 Project Engineer, Radionics-Tyco Healthcare, Burlington, MA, USA

2000 - 2002 Mechanical/Field Service Engineer, Radioncs-Tyco Healthcare, Burlington, MA, USA

Products

Products Most Closely Related to the Proposed Project

1. Manish R, An Z, Habib A, Tuinstra M, Cappelleri DJ. AgBug: Agricultural Robotic Platform

for In-row and Under Canopy Crop Monitoring and Assessment. Proceedings of the ... ASME Design Engineering Technical Conferences. ASME Design Engineering Technical Conferences. 2021 August 17. Available from: https://doi.org/10.1115/DETC2021-68143

2. Kim K, Deb A, Cappelleri DJ. P-AgBot: In-Row & Under-Canopy Agricultural Robot for Monitoring and Physical Sampling. IEEE Robotics & Automation Letters (RA-L). 2022 July; 7(3):7942-7949. DOI: 10.1109/LRA.2022.3187275
3. Kagan C, Arnold D, Cappelleri DJ, Keske C, Turner K. The National Science Foundation (NSF) Engineering Research Center (ERC) for the Internet of Things for Precision Agriculture (IoT4Ag). Computers and Electronics in Agriculture. 2022; 196(106742). Available from: https://doi.org/10.1016/j.compag.2022.106742
4. Deb A, Kim K, Cappelleri DJ. Deep Learning-Based Leaf Detection for Robotic Physical Sampling with P-AgBot. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI, USA. 2023 October; :8291-8297. DOI: 10.1109/IROS55552.2023.10341516
5. Kim K, Deb A, Cappelleri DJ. P-AgSLAM: In-Row and Under-Canopy SLAM for Agricultural Monitoring in Cornfields. IEEE Robotics and Automation Letters. 2024 June; 9(6):4982-4989. DOI: 10.1109/LRA.2024.3386466

Other Significant Products, Whether or Not Related to the Proposed Project

1. McArthur D, Chowdhury A, Cappelleri DJ. Design of the I-BoomCopter Unmanned Aerial Vehicle for Remote Sensor Mounting. ASME Journal of Mechanisms & Robotics (JMR). 2018 January; 10(2):025001. DOI: 10.1115/1.4038973
2. McArthur D, Chowdhury A, Cappelleri DJ. Design of the I-BoomCopter UAV for Environmental Interaction. IEEE International Conference on Robotics and Automation (ICRA). 2017 May.
3. McArthur D, An Z, Cappelleri DJ. Featureless Visual Target Tracking for Human-Guided Remote Sensor Mounting with a UAV. IEEE International Conference on Robotics and Automation : ICRA : [proceedings]. IEEE International Conference on Robotics and Automation. 2020 May.
4. Li J, Teeple C, Wood R, Cappelleri DJ. Modular End-Effector System for Autonomous Robotic Maintenance & Repair. IEEE International Conference on Robotics and Automation (ICRA). 2022 May 23.
5. Li J, Cappelleri DJ. Sim-Suction: Learning a Suction Grasp Policy for Cluttered Environments Using a Synthetic Benchmark. IEEE Transactions on Robotics. 2024; 40:316-331. DOI: 10.1109/TRO.2023.3331679

Certification:

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Cappelleri, David in SciENcv on 2024-06-03 14:48:55

Synergistic Activities

David J. Cappelleri, Ph.D.
Assistant Vice President for Research Innovation, Office of Research
B.F.S. Schaefer Scholar & Professor, School of Mechanical Engineering
Professor, Weldon School of Biomedical Engineering (by Courtesy)
Purdue University

1. Honor/Award: NSF Faculty Early Career Development (CAREER) Award, 2012

2. International Competition Organizer: IEEE RAS Mobile Microrobotics Challenge, 2013-2018

3. Honor/Award: Fellow of the American Society of Mechanical Engineers (ASME), 2024

4. Associate Editor: IEEE Transactions on Robotics (T-RO), January 2024 – present

5. Knowledge Creation/Transfer: 6 issued patents: US 10,709,324; US 10,806489; US 11,091,256; US 11,159,105; US 11,642,185; US 11,905,005

IDENTIFYING INFORMATION:

NAME: Carpin, Stefano

ORCID iD: https://orcid.org/0000-0003-3837-7463

POSITION TITLE: Associate Dean for Research and Graduate Programs

PRIMARY ORGANIZATION AND LOCATION: University of California, Merced, School of Engineering, Merced, California, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Padova, Padova, Not Applicable, N/A, Italy	PHD	02/2003	Industrial Electronics and Computer Science
University of Padova, Padova, Not Applicable, N/A, Italy	MS	11/1999	Electrical Engineering and Computer Science

Appointments and Positions

2024 - present	Associate Dean for Research and Graduate Programs, University of California, Merced, School of Engineering, Merced, California, United States
2016 - present	Professor, University of California, Merced, School of Engineering, Merced, California, United States
2010 - 2016	Associate Professor, University of California, Merced, School of Engineering, Merced, California, United States
2007 - 2010	Assistant Professor, University of California, Merced, School of Engineering, Merced, California, United States
2005 - 2006	Assistant Professor of Computer Science, International University Bremen, School of Engineering and Science, Bremen, Not Applicable, N/A, Germany
2003 - 2004	Research Instructor, International University Bremen, School of Engineering and Science, Bremen, Not Applicable, N/A, Germany

Products

Products Most Closely Related to the Proposed Project

1. A. Dechemi, D. Chatziparaschis, J. Chen, M. Campbell, A. Shamshirgaran, C. Mucchiani, A. Roy-Chowdhury, S. Carpin, K. Karydis. Robotic Assessment of a Crop's Need for Watering. IEEE Robotics and Automation Magazine. 2023; 30(4):52 - 67.
2. E. Sani, A. Sgorbissa, S. Carpin. Improving the ROS 2 Navigation Stack with Real-Time Local Costmap Updates for Agricultural Applications. Proceedeings of the IEEE International Conference on Robotics and Automation; 2024; c2024.
3. A. Grillo, S. Carpin, C.T. Recchiuto, A. Sgorbissa. Trust as a Metric for Auction-based Task Assignment in a Cooperative Team of Robots with Heterogenous Capabilities. Robotics and Autonomous Systems. 2022; :157-104266.
4. Avigal Y., Wong W., Presten M., Theis M., Aeron S., Deza A., Sharma S., Parikh R., Oehme S., Carpin S., Viers J.H., Vougioukas S., Goldberg K.Y.. Simulating Polyculture Farming to

Learn Automation Policies for Plant Diversity and Precision Irrigation. IEEE Transactions on Automation Science and Engineering. 2022; 19(3):1352–1364.

5. T.C. Thayer, S. Carpin. An Adaptive Method for the Stochastic Orienteering Problem. IEEE Robotics and Automation Letters. 2021; 6(2):4185 - 4192.

Other Significant Products, Whether or Not Related to the Proposed Project

1. L. Booth, S. Carpin. Distributed estimation of scalar fields with implicit coordination. In:L. Booth, S. Carpin. , editor. Distributed Autonomous Robotic Systems 16.; 2024; Springer; c2024.
2. F. Betti Sorbelli, S. Carpin, F. Coró, S.K. Das, A. Navarra, C.M. Pinotti. Speeding up Routing Schedules on Aisle-Graphs with Single Access. IEEE Transactions on Robotics. 2022; 38(1):433–447.
3. X. Kan, T. Thayer, S. Carpin, K. Karydis. Task planning on stochastic aisle graphs for precision agriculture. IEEE Robotics and Automation Letters. 2021; 6(2):3287 - 3294.
4. T. Thayer, S. Vougioukas, K. Goldberg, S. Carpin. Multi-Robot Routing Algorithms for Robots Operating in Vineyards. IEEE Transactions on Automation Science and Engineering. 2020; 17(3):1184–1194.
5. S. Carpin, J.L. Susa Rincon. Time constrained exploration using toposemantic spatial models: a reproducbile approach. Robotics and Automation Magazine. 2019; 26(3):78-87.

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Carpin, Stefano in SciENcv on 2024-06-27 17:24:39

Stefano Carpin – Synergistic Activities

1. International Robotics Competitions: elected Executive member of the RoboCup Federation for the term 2006-2009.
2. Associate Editor: IEEE Transactions on Robotics (May 2010 -- May 2014).
3. Associate Editor: IEEE Transactions on Automation Science and Engineering (January 2015 -- January 2019).
4. Associate Editor: IEEE/RSJ International Conference on Intelligent Robots and System (2008-2019, 2023, 2024)
5. Site Director: NSF Engineering Research Center for the Internet of Things for Precision Agriculture (2023-present)

IDENTIFYING INFORMATION:

NAME: Chaudhari, Pratik

ORCID iD: https://orcid.org/0000-0003-4590-1956

POSITION TITLE: Assistant Professor

PRIMARY ORGANIZATION AND LOCATION: Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of California Los Angeles, Los Angeles, California, USA	PHD	06/2018	Computer Science
Massachusetts Institute of Technology, Cambridge, Massachusetts, USA	OTH	05/2014	Aeronautics and Astronautics
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	MS	05/2012	Aeronautics and Astronautics
Indian Institute of Technology Bombay, Mumbai, Maharashtra, India	BOTH	05/2010	Aerospace Engineering

Appointments and Positions

2019 - present	Assistant Professor, Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2021 - present	Visiting Academic, Amazon Web Services, Palo Alto, CA, United States
2019 - present	Assistant Professor, Computer and Information Science, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2018 - 2019	Senior Applied Scientist, Amazon Web Services, Pasadena, California, United States
2018 - 2019	Postdoctoral Scholar, Computing and Mathematical Sciences, California Institute of Technology, Pasadena, Pennsylvania, United States
2014 - 2014	Principal Autonomous Vehicle Engineer, NuTonomy Inc., Boston, Massachusetts, United States

Products

Products Most Closely Related to the Proposed Project

1. Prabhu A, Liu X, Spasojevic I, Wu Y, Shao Y, Ong D, Lei J, Green C, Chaudhari P, Kumar V. Robots in the wild: Fine-grained metric-semantic mapping and diameter estimation in forests with autonomous UAVs. Mechanical Systems and Signal Processing (MSSP). 2023.
2. Ramesh R, Chaudhari P. Model Zoo: A Growing "Brain" That Learns Continually. ICLR. 2022.
3. Cheng D, Ojeda F, Prabhu A, Liu X, Zhu A, Green P, Ehsani R, Chaudhari P, Kumar V. TreeScope: An agricultural robotics dataset for LiDAR-Based mapping of trees in forests and orchards. ICRA. 2024.

4. He S, Hsu C, Ong D, Shao Y, Chaudhari P. Active perception using neural radiance fields. ACC. 2024.
5. Castro L, Chaudhari P, Tumova J, Karaman S, Frazzoli E, Rus D. Incremental sampling-based algorithms for minimum-violation motion planning. CDC. 2013.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Mao J, Griniasty I, Teoh H, Ramesh R, Yang R, Transtrum M, Sethna J, Chaudhari P. The Training Process of Many Deep Networks Explores the Same Low-Dimensional Manifold. PNAS. 2024; 121(12):e2310002121.
2. Chaudhari P, Choromanska A, Soatto S, LeCun Y, Baldassi C, Borgs C, Chayes J, Sagun L, Zecchina R. Entropy-SGD: Biasing gradient descent into wide valleys. ICLR. 2017.
3. Wang R, *Chaudhari P, *Davatzikos C. Bias in machine learning models can be significantly mitigated by careful training: Evidence from neuroimaging studies. PNAS. 2023; 120(6):e2211613120.
4. Yang R, Mao J, Chaudhari P. Does the data induce capacity control in deep learning?. ICML. 2022.
5. Gao Y, Chaudhari P. An information-geometric distance on the space of tasks. ICML. 2021.

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Chaudhari, Pratik in SciENcv on 2024-07-17 10:24:31

Name: Pratik Chaudhari
ORCID iD: pratikac
Position Title: Assistant Professor
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. Ongoing development of a course titled "Principles of Deep Learning". This has drawn 500+ undergraduate and graduate students from across Engineering, Arts and Sciences. I have developed a large body of publicly-available course material and programming exercises. I prepared an online version of this course that was recently launched as a part of the Penn Online Master's program and Coursera; it is expected that 100s of students will take this course each year.
2. As the Principal Autonomous Vehicle Engineer and an early employee of NuTonomy (now Hyundai-Aptiv Motional), my research on safe, urban, autonomous driving helped launch the world's first autonomous taxi service in 2016 in Singapore. NuTonomy is a large company today and operates in Boston, Los Angeles and Singapore.
3. Organized the "Deep Learning through Information Geometry" workshop at NeurIPS 2020. This featured 6 keynotes by experts on deep learning from across the world, 24 accepted publications and about 100 attendees. I also helped organize a Winter School on "Quantitative Systems Biology" at the International Center for Theoretical Physics (ICTP) in Trieste, Italy which was focused on problems at the intersection of biophysics and deep learning.
4. I have advised 14 doctoral students (two women) across CIS, ESE, Bio-Engineering, Applied Math and Physics. Since 2019, I have mentored 100+ undergraduate students on research projects, many of these students were conducting research for the first time.
5. Lectured 57 high-school students in Penn Rising Scholar Success Academy which is a postsecondary access program designed to introduce different educational and career pathways to students.

IDENTIFYING INFORMATION:

NAME: Crawford, Melba

POSITION TITLE: Professor of Civil Engineering, Electrical and Computer Engineering (courtesy), and Agronomy

PRIMARY ORGANIZATION AND LOCATION: Purdue University, West Lafayette, IN, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Ohio State University, Columbus, Ohio, United States	PHD	08/1981	Industrial and Systems Engineering
University of Illinois, Urbana, Illinois, United States	MS	05/1973	Civil Engineering
University of Illinois, Urbana, Illinois, United States	BS	08/1970	Civil Engineering

Appointments and Positions

2006 - present	Professor of Civil Engineering, Electrical and Computer Engineering (courtesy), and Agronomy, Purdue University, West Lafayette, IN, United States
2009 - 2019	Associate Dean of Engineering for Research, Purdue University, West Lafayette, IN, USA
2006 - 2009	Assistant Dean for Interdisciplinary Research, College of Agriculture and College of Engineering, Purdue University, West Lafayette, IN, USA
1991 - 2005	Professor of Mechanical Engineering, The University of Texas at Austin, Austin, TX, USA
1986 - 1991	Associate Professor of Mechanical Engineering, The University of Texas at Austin, Austin, TX, USA
1980 - 1986	Assistant Professor of Mechanical Engineering, The University of Texas at Austin, Austin, , TX, USA
1977 - 1980	Instructor, The University of Texas at Dallas, Richardson, TX, USA

Products

Products Most Closely Related to the Proposed Project

1. Liu W, Quijano K, Crawford MM. YOLOv5-tassel: Detecting Tassels in RGB UAV Imagery with Improved YOLOv5 Based on Transfer Learning. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2022 September 13; 15:8085. DOI: 10.1109/JSTARS.2022.3206399
2. Wang T, Crawford MM, Tuinstra MR. A Novel Transfer Learning Framework for Sorghum Biomass Prediction Using UAV-based Remote Sensing Data and Genetic Markers. Frontiers in Plant Science. 2023 April 11; 14. Available from: https://www.frontiersin.org/articles/10.3389/fpls.2023.1138479/full DOI: 10.3389/fpls.2023.1138479

3. Pignotti G, Crawford M, Han E, Williams M, Chaubey I. SMAP Soil Moisture Data Assimilation Impacts on Water Quality and Crop Yield Predictions in Watershed Modeling. Journal of Hydrology. 2023; 617:129122. DOI: 10.1016/j.jhydrol.2023.129122
4. Aviles Toledo C, Crawford M, Tuinstra MR. Integrating Multi-Modal Remote Sensing, Deep Learning, and Attention Mechanisms for Yield Prediction in Plant Breeding Experiments. Frontiers in Plant Science. Forthcoming.
5. Nazeri B, Crawford MM, Tuinstra MR. Estimating Leaf Area Index in Row Crops Using Wheel-Based and Airborne Discrete Return Lidar Data. Frontiers in Plant Science. 2021 November 29; 23(12):740322. DOI: 10.3389/fpls.2021.740322

Other Significant Products, Whether or Not Related to the Proposed Project

1. Zhang Z, Crawford M. An Adaptive Multiview Active Learning Approach for Spectral-Spatial Classification of Hyperspectral Images. IEEE Transactions on Geoscience and Remote Sensing. 2019; 58(4):2557. DOI: 10.1109/TGRS.2019.2952319
2. Pasolli E, Yang HL., Crawford MM. Active-metric Learning for Classification of Remotely Sensed Hyperspectral Images. IEEE Transactions on Geoscience and Remote Sensing. 2017; 55(11):6594. DOI: 10.1109/TGRS.2015.2490482
3. Cai E, Baireddy S, Yang C, Crawford MM, Delp EJ. Deep Transfer Learning For Plant Center Localization. IEEE/CVF 2020 Agriculture-Vision Workshop. 2020 June 14; :62. Available from: https://openaccess.thecvf.com/content_CVPRW_2020/html/w5/Cai_Deep_Transfer_Learning_f
4. Yang HL, Crawford M. Spectral and Spatial Proximity Based Manifold Alignment for Multitemporal Hyperspectral Image Classification. IEEE Transactions on Geoscience and Remote Sensing. 2016; 8(2):845. DOI: 10.1109/TGRS.2015.2449736
5. Yaghmour A, Prasad S, Crawford M. Attention Guided Semi-Supervised Generative Transfer Learning for Hyperspectral Image Analysis. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. Forthcoming.

Certification:

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Certified by Crawford, Melba in SciENcv on 2024-06-22 17:08:30

Synergistic Activities

Name: Melba Crawford

Institution: Purdue University

1. Developed an international research collaboration with the University of Cape Town and a technology startup (DroneSAR) focused on high resolution soil moisture sensing and product development from a SAR sensor flown on a UAV.

2. Served in multiple leadership roles in the IEEE over the past two decades. Currently serves as the Past Treasurer of the Technical Activities Board of the IEEE and on the Finance Committee of the IEEE Foundation.

3. Developed an educational collaboration with the U of Pavia to deliver graduate level coursework on UAV technologies in Agriculture. Delivered the first course in February 2024, with plans to extend the curriculum.

4. Engaging with GRYFN, a Purdue startup focused on UAV technology to extend software offerings to include algorithms for analysis of UAV data from hyperspectral and LiDAR data.

IDENTIFYING INFORMATION:

NAME: Ehsani, Reza

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: University of California, Merced, Merced, California, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of California, Davis, Davis, California, United States	PHD	06/2000	Agricultural and Biological Engineering
University of Tehran, Tehran, Tehran, Iran	MS	06/1992	Agricultural Engineering
University of Tehran, Tehran, Tehran, Iran	BS	06/1988	Agricultural Engineering

Appointments and Positions

2017 - present Professor, University of California, Merced, Merced, California, United States

Products

Products Most Closely Related to the Proposed Project

1. Ebrahimi I, de Castro R, Ehsani R, Brillante L, Feng S. Advancing grape chemical analysis through machine learning and multi-sensor spectroscopy. Journal of Agriculture and Food Research. 2024; 16:101085. issn: 2666-1543
2. Dong X, Kim W, Yu Z, Oh J, Ehsani R, Lee K. Improved voxel-based volume estimation and pruning severity mapping of apple trees during the pruning period. Computers and Electronics in Agriculture. 2024; 219:108834. issn: 0168-1699
3. Muhammed D, Ahvar E, Ahvar S, Trocan M, Montpetit M, Ehsani R. Artificial Intelligence of Things (AIoT) for smart agriculture: A review of architectures, technologies and solutions. Journal of Network and Computer Applications. 2024; :103905. issn: 1084-8045
4. Dong X, Kim W, Zheng Y, Oh J, Ehsani R, Lee K. Three-dimensional quantification of apple phenotypic traits based on deep learning instance segmentation. Computers and Electronics in Agriculture. 2023; 212:108156. issn: 0168-1699
5. Niu H, Wang D, Ehsani R, Chen Y. Tree-level yield estimation using UAV-based vegetation indices and plant physiology-informed machine learning. 2022 International Conference on Unmanned Aircraft Systems (ICUAS). 2022; :1614-1619. isbn: 1665405937

Other Significant Products, Whether or Not Related to the Proposed Project

1. Tituaña L, Gholami A, He Z, Xu Y, Karkee M, Ehsani R. A small autonomous field robot for strawberry harvesting. Smart Agricultural Technology. 2024; 8:100454. issn: 2772-3755
2. de Castro Megías A, Pérez-Roncal C, Thomasson J, Ehsani R, López-Maestresalas A, Yang C, Jarén C, Wang T, Cribben C, Marin D. Applications of sensing for disease detection. Sensing

approaches for precision agriculture. 2021; :369-398. isbn: 3030784304

3. Li J, Li L, Pang Z, Kolbasov VG, Ehsani R, Carter EW, Wang N. Developing Citrus Huanglongbing (HLB) Management Strategies Based on the Severity of Symptoms in HLB-Endemic Citrus-Producing Regions. Phytopathology. 2019 Apr;109(4):582-592. PubMed PMID: 30418089.
4. Lu J, Ehsani R, Shi Y, de Castro AI, Wang S. Detection of multi-tomato leaf diseases (late blight, target and bacterial spots) in different stages by using a spectral-based sensor. Sci Rep. 2018 Feb 12;8(1):2793. PubMed Central PMCID: PMC5809472.
5. Choi D, Lee W, Ehsani R, Schueller J, Roka F. Detection of dropped citrus fruit on the ground and evaluation of decay stages in varying illumination conditions. Computers and Electronics in Agriculture. 2016; 127:109-119. issn: 0168-1699

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Certified by Ehsani, Reza in SciENcv on 2024-06-28 16:58:54

Synergistic Activities - Reza Ehsani

• Serve as an engineer member of the pistachio working group to develop programs to help pistachio growers improve their productivity and profit.

• Organized and chaired several workshops, field days, and conferences related to new technologies in agriculture and gave several invited keynote speeches on applications of advanced technology in agriculture.

• Hosted and supervised three undergraduate students for eight weeks of training under an NSF-funded Research Experience for Undergraduate (REU) program in water resources.

• Developed an undergraduate course entitled “Innovative Technologies in Agriculture.” The course introduced and covered topics about site-specific crop management and its benefits for food production systems.

• Associate Editor of the Journal of Applied Engineering in Agriculture and Transactions of the ASABE.

IDENTIFYING INFORMATION:

NAME: Eisenstadt, William Richard

ORCID iD: https://orcid.org/0000-0003-2920-6638

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Stanford University , Stanford , California, United States	PHD	01/1986	Electrical Engineering
Stanford University , Stanford , California, United States	MS	06/1981	Electrical Engineering
Stanford University , Stanford , California, United States	BS	06/1979	Electrical Engineering

Appointments and Positions

2007 - present	Professor, University of Florida, Gainesville, Florida, United States
2007 - present	Professor, University of Florida, Gainesville, Florida, United States
1990 - 2007	Associate Professor, University of Florida, Gainesville, Florida, United States
1986 - 1990	Assistant Professor, University of Florida, Gainesville, Florida, United States
1984 - 1986	Provisional Assistant Professor, University of Florida, Gainesville, Florida, United States
1979 - 1983	Research Assistant , Stanford University , Stanford , California, United States

Products

Products Most Closely Related to the Proposed Project

1. Nicolas F, Migliaccio K, Hoogenboom G, Rathinasabapathi B, Eisenstadt W. Assessing the Potential Impact of Climate Change on Rice Yield in the Artibonite Valley of Haiti Using the CSM–CERES-Rice Model. Transactions of the ASABE. 2020; 63(5):1385–1400. Available from: https://elibrary.asabe.org/abstract.asp?AID=51767&t=3&dabs=Y&redir=&redirType= DOI: 10.13031/trans.13868
2. Ashton M, Appen I, Firlak M, Stanhope N, Schmidt C, Eisenstadt W, Hur B, Hardy J. Wirelessly triggered bioactive molecule delivery from degradable electroactive polymer films. Polymer International. 2020 August 06; 70(4):467-474. Available from: https://onlinelibrary.wiley.com/doi/10.1002/pi.6089 DOI: 10.1002/pi.6089
3. WIRELESS SMART MOSQUITO AND INSECT TRAP DEVICE, NETWORK AND METHOD OF COUNTING A POPULATION OF THE MOSQUITES OR INSECTS. US 10,588,306. 2015 April.
4. Hur B, Eisenstadt W. Progress in development of the low-power wireless multiple temperature sensor pole for pesticide, agriculture, and mosquito research. SoutheastCon 2015. SoutheastCon

2015; ; Fort Lauderdale, FL, USA. IEEE; c2015. Available from: http://ieeexplore.ieee.org/document/7132963/ DOI: 10.1109/SECON.2015.7132963

5. Hur B, Eisenstadt W. Low-power wireless climate monitoring system with RFID security access feature for mosquito and pathogen research. 2015 First Conference on Mobile and Secure Services (MOBISECSERV). 2015 First Conference on Mobile and Secure Services (MOBISECSERV); ; Gainesville, FL, USA. IEEE; c2015. Available from: http://ieeexplore.ieee.org/document/7072871/ DOI: 10.1109/MOBISECSERV.2015.7072871

Other Significant Products, Whether or Not Related to the Proposed Project

1. Eisenstadt W, Roos M, Morris D, González-Jiménez J, Mounet C, Barragan M, Leger G, Cilici F, Lauga-Larroze E, Mir S, Bourdel S, Margalef-Rovira M, Alaji I, Ghanem H, Ducournau G, Gaquiere C. Special Session on RF/5G Test. 2022 IEEE European Test Symposium (ETS). 2022 IEEE European Test Symposium (ETS); ; Barcelona, Spain. IEEE; c2022. Available from: https://ieeexplore.ieee.org/document/9810461/ DOI: 10.1109/ETS54262.2022.9810461
2. Yoon J, Eisenstadt W. Embedded Loopback Test for RF ICs. IEEE Transactions on Instrumentation and Measurement. 2005 October; 54(5):1715-1720. Available from: http://ieeexplore.ieee.org/document/1514620/ DOI: 10.1109/TIM.2005.855091
3. Microwave Differential Circuit Design Using Mixed-Mode S-parameters. 2006 04. isbn: 1-58053-933-5
4. Bockelman D, Eisenstadt W. Pure-mode network analyzer for on-wafer measurements of mixed-mode S-parameters of differential circuits. IEEE Transactions on Microwave Theory and Techniques. 1997; 45(7):1071–1077. Available from: http://ieeexplore.ieee.org/document/598443/ DOI: 10.1109/22.598443
5. Eisenstadt W, Eo Y. S-parameter-based IC interconnect transmission line characterization. IEEE Transactions on Components, Hybrids, and Manufacturing Technology. 1992; 15(4):483–490. Available from: http://ieeexplore.ieee.org/document/159877/ DOI: 10.1109/33.159877

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Eisenstadt, William Richard in SciENcv on 2024-06-12 09:21:21

Name: Eisenstadt, William Richard
ORCID iD: 0000-0003-2920-6638
Position Title: Professor
Primary Organization and Location: University of Florida, Gainesville, Florida

Synergistic Activities:

1. Prof. Eisenstadt and his group invented mixed-mode and differential s-parameters in 1994 to characterize differential circuit behavior that occurs RF frequencies. Before this research, there was no method for accurately characterizing RF, microwave and millimeter-wave differential circuits and transmission structures. Prof. Eisenstadt is co-author of three fundamental patents showing the measurement, probing and calibration of RF differential circuits, one of these patents won the Motorola patent of the year. In addition, he is co-author of 10 journal papers and first author of a microwave design book, "Microwave Differential Circuit Design Using Mixed-Mode S-parameters," on this subject. The book expanded these basic techniques into a design methodology. This technique was adopted by the Microwave measurement companies and is now commonly used in automated network analyzers.

2. Dr. Eisenstadt and his students developed extensive modeling and measurement techniques for characterizing IC interconnect response and high-speed I/O through the course of three decades. Prof. Eisenstadt began his career taking the first picosecond optoelectronic based measurements of silicon IC interconnect as part of his PhD. He then developed compact interconnect modeling sponsored by SRC and a method of extracting on-chip interconnect Telegrapher's equation parameters from s-parameters. Further papers and SRC industry talks demonstrated how to model signals on an IC interconnect bus switch including non-linear drivers and crosstalk. His recent work has focused on on-chip self-test methods of characterizing interconnect and power line response planar and 3D ICs and on characterizing the performance of high speed I/O as it transmits through the chip and package system for the SRC and its member companies.

3. Prof. Eisenstadt has developed designs and prototypes of a smart bioassay cage for mosquito spray testing sponsored by the CDC. This work results in new real time measurements of the insecticide droplets for evaluating mosquito pesticide morality and enables much more effective introduction of new pesticides as old ones lose efficacy. Mosquito control is essential for arbovirus disease control, (Malaria, Zika, West Nile Virus, Dengue, etc.). This device is intended to be commercialized and distributed to US and world mosquito districts in the US.

4. Prof. Eisenstadt under the USAID AREA project created weather stations for micro-climate measurements to support Haitian agriculture. Weather stations were installed in four Haitian agricultural research stations. Eisenstadt developed, presented, and had translated four USAID-sponsored workshops for training Haitian engineers in the 1) maintenance of weather stations, 2) the assembly and programing of weather stations and the use of weather data for improved agriculture, 3) programing IoT sensors systems and 4) a Weather Station Technicians Workshop. This education effort allows Haitian support of maintenance of the stations in the future.

5. Prof. Eisenstadt is a strong contributor to the NSF ERC IoT4AG leading communication and sensor projects for field sensing and crop improvement in agriculture research fields in Quincy, Florida. Prof. Eisenstadt is currently developing IoT communications and sensing for Pure Biomass Inc. as part of the NSF ERC IoT4AG. Dr. Eisenstadt and his students demonstrate these techniques on the IoT4Ag testbeds and report the results to the NSF IoT4Ag center companies in workshops and reviews.

IDENTIFYING INFORMATION:

NAME: Field, Kristin Lynne

POSITION TITLE: Director of Education and Inclusivity

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, IoT4Ag ERC, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Monell Chemical Senses Center, Philadelphia, Pennsylvania, United States	Postdoctoral Fellow	10/2005 - 06/2008	Behavioral Biology-Ecology
The Ohio State University, Columbus, Ohio, United States	PHD	05/2004	Evolution, Ecology & Organismal Biology
Illinois State University, Normal, Illinois, United States	BA	05/1993	English, Global Studies

Appointments and Positions

2024 - present Director of Education and Inclusivity, University of Pennsylvania, IoT4Ag ERC, Philadelphia, Pennsylvania, United States

2022 - 2024 Director of Education & Program Coordinator, University of Pennsylvania, NSF NRT Interdiscip Training in Data Driven Soft Materials Research & Science Policy, Philadelphia, Pennsylvania, United States

2015 - 2024 Education and Professional Development Director, University of Pennsylvania, Singh Center for Nanotechnology, Philadelphia, Pennsylvania, United States

2015 - 2022 Co-PI, Education & Professional Development Director, University of Pennsylvania, REACT Program - an NSF PIRE , Philadelphia, Pennsylvania , United States

2013 - 2016 Director of Programs, University of Pennsylvania, Nano/Bio Interface Center, Philadelphia, Pennsylvania, United States

2008 - 2013 Staff Asst; Asst Director; Assoc Director of Programs, University of Pennsylvania, Penn Genome Frontiers Institute, Philadelphia, Pennsylvania, United States

Products

Products Most Closely Related to the Proposed Project

1. Field KL, Marcano-Delgado A, Ortiz-Ortiz D, Ramos Colon I. Panel Session Summary and Recommendations from "Best practices for recruiting, retaining, and supporting graduate students from MSIs". [Internet]. Philadelphia, PA: NRT Soft AE Program; 2024 March. Available from: https://soft-ae.seas.upenn.edu/wp-content/uploads/2024/03/Panel_Summary-Recommendations_Final.pdf

Other Significant Products, Whether or Not Related to the Proposed Project

1. Field KL, Beauchamp GK, Kimball BA, Mennella JA, Bachmanov AA. Bitter avoidance in guinea pigs (Cavia porcellus) and mice (Mus musculus and Peromyscus leucopus). J Comp Psychol. 2010 Nov;124(4):455-9. PubMed Central PMCID: PMC2999000.
2. Field KL, Bachmanov AA, Mennella JA, Beauchamp GK, Kimball BA. Protein hydrolysates are

avoided by herbivores but not by omnivores in two-choice preference tests. PLoS One. 2009;4(1):e4126. PubMed Central PMCID: PMC2606031.

3. Field KL, Kimball BA, Mennella JA, Beauchamp GK, Bachmanov AA. Avoidance of hydrolyzed casein by mice. Physiol Behav. 2008 Jan 28;93(1-2):189-99. PubMed Central PMCID: PMC2254509.
4. Waite TA, Field KL. Foraging: Behavior and Ecology. Stephens DW, Brown JS, Ydenberg YC, editors. Chicago, London: University of Chicago; 2007. Foraging with Others: Games Social Foragers Play; p.331-362.
5. Field KL, Waite TA. Absence of female conspecifics induces homosexual behaviour in male guppies. Animal Behaviour. 2004 December; 68(6):1381-1389. Available from: https://doi.org/10.1016/j.anbehav.2003.12.022

Certification:

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Field, Kristin Lynne in SciENcv on 2024-06-14 15:34:03

Field, Kristin L.
Synergistic Activities

Training Graduate Students to work across disciplines on complex societal problems: Co-created and co-taught a graduate-level semester-long course at Penn entitled “Societal Grand Challenges at the Interface of Technology and Policy” (Spring 2023, Spring 2024). Students enroll from a diversity of STEM and non-STEM graduate programs. After setting the stage with technology and policy background material and reviewing case studies, teams of students tackle an energy-transition problem of their choice for their final projects. I presented our course at the American Solar Energy Society *Solar 2024: Connecting Technology & Policy* Conference’s Education and Training Track (Washington, DC, May 2024).
Partnership Building: Co-wrote an awarded NSF NRT-PREM Collaborative Supplement proposal (2023-2024, $150k for our NRT and $150k for the PREM at University of Puerto Rico Humacao); Together, with the PI of the PREM, we created programming for the PREM undergraduates. I organized our NRT Soft AE graduate trainees to play critical roles in delivering the seminars and coding workshops. For the PREM December 2023 meeting, the PREM PI and I collaborated on a session that focused on best practices for recruiting, retaining and supporting graduate students who come from MSIs (summary article is available on the NRT Soft AE website).
Organizing a workshop for students to see how science and policy intersect: I led efforts to include a “Science Outside the Laboratory” workshop, a program created and run by Arizona State University, into our NRT Soft AE Program’s offerings. This included writing it into our NRT proposal, finding a funding partner, and co-organizing the week-long workshop in Washington, DC with ASU colleagues (May 2024, N=14 Penn Graduate Student participants for this pilot year).
Exploration of ways to direct engineering research and education towards community-identified needs related to extreme urban heat: Co-wrote the proposal and co-manage the funded pilot program that supports partnership building with other individuals and organizations working on extreme heat and for student projects related to extreme urban heat (https://soft-ae.seas.upenn.edu/community/urban-heat/).

IDENTIFYING INFORMATION:

NAME: Hestir, Erin

ORCID iD: https://orcid.org/0000-0002-4673-5745

POSITION TITLE: Associate Professor

PRIMARY ORGANIZATION AND LOCATION: University of California Merced, Department of Civil & Environmental Engineering, Merced, California, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of California Davis, Davis, California, United States	PHD	06/2010	Geography
University of California Berkeley, Berkeley, California, United States	BA	12/2004	Geography

Appointments and Positions

2019 - present	Associate Professor , University of California Merced, Department of Civil & Environmental Engineering, Merced, California, United States
2023 - present	Director, Center for Information Technology and Research in the Interest of Society (CITRIS) & the Banatao Institute Merced, Merced, California, United States
2020 - 2023	Associate Director , Center for Information Technology and Research in the Interest of Society (CITRIS) & the Banatao Institute Merced, Merced, California, United States
2017 - 2019	Assistant Professor, University of California Merced, Department of Civil & Environmental Engineering, Merced, California, United States
2014 - 2017	Assistant Professor, North Carolina State University, Department of Marine, Earth & Atmospheric Sciences, Raleigh, North Carolina, United States
2013 - 2019	Adjunct Senior Lecturer, University of Southern Queensland, Civil Engineering and Surveying, Towoomba , Not Applicable, N/A, Australia
2011 - 2014	Postdoctoral Fellow, Commonwealth Scientific & Industrial Research Organization, Environmental Earth Observation, Canberra, Not Applicable, N/A, Australia
2010 - 2011	Postdoctoral Fellow, University of California Davis, Department of Land, Air & Water Resources , Davis, California, United States

Products

Products Most Closely Related to the Proposed Project

1. Basinger N, Hestir E, Jennings K, Monks D, Everman W, Jordan D. Detection of Palmer amaranth (*Amaranthus palmeri*) and large crabgrass (*Digitaria sanguinalis*) with in situ hyperspectral remote sensing. I. Effects of weed density and soybean presence. Weed Science. 2022 January 24; 70(2):198-212. Available from: https://www.cambridge.org/core/product/identifier/S0043174521000813/type/journal_article DOI: 10.1017/wsc.2021.81
2. Bolch E, Hestir E, Khanna S. Performance and Feasibility of Drone-Mounted Imaging

Spectroscopy for Invasive Aquatic Vegetation Detection. Remote Sensing. 2021 February 06; 13(4):582-. Available from: https://www.mdpi.com/2072-4292/13/4/582 DOI: 10.3390/rs13040582

3. Basinger N, Jennings K, Hestir E, Monks D, Jordan D, Everman W. Phenology affects differentiation of crop and weed species using hyperspectral remote sensing. Weed Technology. 2020 August 18; 34(6):897-908. Available from: https://www.cambridge.org/core/product/identifier/S0890037X20000925/type/journal_article DOI: 10.1017/wet.2020.92
4. Nesslage J, Barreto B, Weingram A, Hestir E. A Machine Learning Approach for High Resolution Fractional Vegetation Cover Estimation Using Planet Cubesat and RGB Drone Data Fusion. IGARSS 2023-2023 IEEE International Geoscience and Remote Sensing Symposium. 2023; :4879-4882. isbn: 9798350320107
5. Hestir E, Wilson A, Cardoso A, Slingsby J, Forbes C. The NASA Biodiversity Survey of the Cape (BioSCape). Hyperspectral/Multispectral Imaging and Sounding of the Environment. 2023; :HM2C-3.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Ade C, Khanna S, Lay M, Ustin S, Hestir E. Genus-Level Mapping of Invasive Floating Aquatic Vegetation Using Sentinel-2 Satellite Remote Sensing. Remote Sensing. 2022 June 23; 14(13):3013-. Available from: https://www.mdpi.com/2072-4292/14/13/3013 DOI: 10.3390/rs14133013
2. Bolch E, Santos M, Ade C, Khanna S, Basinger N, Reader M, Hestir E. Remote Detection of Invasive Alien Species. In: Cavender-Bares J, Gamon J, Townsend P, editors. Remote Sensing of Plant Biodiversity [Internet] Cham: Springer International Publishing; 2020. Chapter Chapter 12267-307p. Available from: http://link.springer.com/10.1007/978-3-030-33157-3_12 DOI: 10.1007/978-3-030-33157-3_12
3. Hestir E, Brando V, Bresciani M, Giardino C, Matta E, Villa P, Dekker A. Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission. Remote Sensing of Environment. 2015 September; 167:181-195. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0034425715300237 DOI: 10.1016/j.rse.2015.05.023
4. Hestir E, Greenberg J, Ustin S. Classification Trees for Aquatic Vegetation Community Prediction From Imaging Spectroscopy. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2012 October; 5(5):1572-1584. Available from: https://ieeexplore.ieee.org/document/6302210/ DOI: 10.1109/JSTARS.2012.2200878
5. Hestir E, Khanna S, Andrew M, Santos M, Viers J, Greenberg J, Rajapakse S, Ustin S. Identification of invasive vegetation using hyperspectral remote sensing in the California Delta ecosystem. Remote Sensing of Environment. 2008 November; 112(11):4034-4047. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0034425708002046 DOI: 10.1016/j.rse.2008.01.022

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Certified by Hestir, Erin in SciENcv on 2024-06-28 16:31:00

Synergistic Activities

Erin Hestir
Associate Professor
https://orcid.org/0000-0002-4673-5745
University of California Merced

1. **Service to the IoT4Ag Engineering Research Center.** Executive Committee. Provides guidance on the research directions of the Center, including review of existing projects and new projects within the Center.
2. **URM Outreach and Workforce Development.** Faculty lead of the *!Valle! Get your Start in Tech* intensive workshop program designed to increase opportunities for women and historically under-represented minority students in technology research. Focused on students from 2-year and 4-year colleges California's Central Valley. Since 2018, the program has served over 130 students, with significant outcomes in increasing self-efficacy and sense-of-belonging, and access to internship, research, and graduate school placement.
3. **Research Leadership**. Co-Principal Investigator & Aquatic Lead, Biodiversity Survey of the Cape (BioSCape), NASA. Led NASA's first biodiversity-focused airborne campaign, consisting of four state of the art NASA instruments (3 imaging spectrometers and 1 laser altimeter) on board two NASA aircraft, and a science team consisting over 150 scientists, students and conservation practitioners organized under 19 PI-led projects. Ensured successful data collection for all PI-led projects and focus on enabling inclusive international scientific collaboration and impact on conservation.
4. **Service to the Research Community**. Science Peer Review Panel and Subject Matter Expert for NASA Surface Biology and Geology VSWIR Satellite Mission. Provide rigorous, independent evaluation of the SBG-VSWIR Project Science Team plans and progress, evaluates the project requirements to determine if they are responsive to the program's objectives for the project and represent achievable capabilities. This review also evaluates the status of the requirement decomposition and traceability, thus serving as a de facto gate for project level milestone reviews.
5. **Service to the Research Community**. User Working Group, Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) for Biogeochemical Dynamics and Ocean Biology Distributed Active Archive Center (OB.DAAC) data and distribution centers. External advisory group tasked to assist in defining goals, provide oversight and guidance on dataset acquisition, development of products, user support and operation functions, recommend annual work plan and advise on long-term planning and review interactions between NASA's Earth Science missions and the DAACs.

IDENTIFYING INFORMATION:

NAME: Kagan, Cherie

ORCID iD: https://orcid.org/0000-0001-6540-2009

POSITION TITLE: Stephen J Angello Professor

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Department of Electrical & Systems Engineering, Department of Materials Science and Engineering, Department of Chemistry, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	PHD	07/1996	Materials Science and Engineering
University of Pennsylvania, Philadelphia, Pennsylvania, United States	BENG	05/1991	Materials Science and Engineering
University of Pennsylvania, Philadelphia, Pennsylvania, United States	BA	05/1991	Mathematics

Appointments and Positions

2007 - present	Stephen J Angello Professor, University of Pennsylvania, Department of Electrical & Systems Engineering, Department of Materials Science and Engineering, Department of Chemistry, Philadelphia, Pennsylvania, United States
2019 - 2024	Associate Dean for Research, University of Pennsylvania, School of Engineering and Applied Science, Philadelphia, Pennsylvania, United States
2004 - 2006	Manager, Molecular Assemblies and Devices Group, IBM T. J. Watson Research Center, Yorktown Heighs, New York, United States
2000 - 2004	Research Staff Member, IBM T. J. Watson Research Center, Yorktown Heights, New York, United States
1998 - 1999	Postdoctoral Fellow, IBM T. J. Watson Research Center, Yorktown Heights, New York, United States
1996 - 1998	Postdoctoral Fellow, Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey, United States

Products

Products Most Closely Related to the Proposed Project

1. Xu J, Zhao T, Zaccarin AM, Du X, Yang S, Ning Y, Xiao Q, Kramadhati S, Choi YC, Murray CB, Olsson RH 3rd, Kagan CR. Chemically Driven Sintering of Colloidal Cu Nanocrystals for Multiscale Electronic and Optical Devices. ACS Nano. 2024 Jul 9;18(27):17611-17621. PubMed PMID: 38916981.
2. Mallavarapu. TiO2 Metasurfaces with Visible Quasi-Guided Mode Resonances via Direct Imprinting of Aqueous Nanocrystal Dispersions. ACS Applied Nanomaterials. 2023. DOI:

10.1021/acsanm.3c03507

3. Kagan C, Arnold D, Cappelleri D, Keske C, Turner K. Special report: The Internet of Things for Precision Agriculture (IoT4Ag). Computers and Electronics in Agriculture. 2022 May; 196:106742-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S016816992200059X DOI: 10.1016/j.compag.2022.106742
4. Kagan C, Arnold D, Allen M, Olsson R. IoT4Ag: MEMS-Enabled Distributed Sensing, Communications, And Information Systems for The Internet Of Things For Precision Agriculture. 2021 IEEE 34th International Conference on Micro Electro Mechanical Systems (MEMS). 2021 IEEE 34th International Conference on Micro Electro Mechanical Systems (MEMS); ; Gainesville, FL, USA. IEEE; c2021. Available from: https://ieeexplore.ieee.org/document/9375346/ DOI: 10.1109/MEMS51782.2021.9375346
5. Chen W, Wu G, Zhang M, Greybush N, Howard-Jennings J, Song N, Stinner F, Yang S, Kagan C. Angle-Independent Optical Moisture Sensors Based on Hydrogel-Coated Plasmonic Lattice Arrays. ACS Applied Nano Materials. 2018 March 06; 1(3):1430-1437. Available from: https://pubs.acs.org/doi/10.1021/acsanm.8b00268 DOI: 10.1021/acsanm.8b00268

Other Significant Products, Whether or Not Related to the Proposed Project

1. Kagan C, Lifshitz E, Sargent E, Talapin D. Building devices from colloidal quantum dots. Science. 2016 August 26; 353(6302):-. Available from: https://www.science.org/doi/10.1126/science.aac5523 DOI: 10.1126/science.aac5523
2. Kagan C, Murray C. Charge transport in strongly coupled quantum dot solids. Nature Nanotechnology. 2015 November 9; 10(12):1013-1026. Available from: https://www.nature.com/articles/nnano.2015.247 DOI: 10.1038/nnano.2015.247
3. Choi J, Wang H, Oh S, Paik T, Sung P, Sung J, Ye X, Zhao T, Diroll B, Murray C, Kagan C. Exploiting the colloidal nanocrystal library to construct electronic devices. Science. 2016 April 08; 352(6282):205-208. Available from: https://www.science.org/doi/10.1126/science.aad0371 DOI: 10.1126/science.aad0371
4. Choi J, Fafarman A, Oh S, Ko D, Kim D, Diroll B, Muramoto S, Gillen J, Murray C, Kagan C. Bandlike Transport in Strongly Coupled and Doped Quantum Dot Solids: A Route to High-Performance Thin-Film Electronics. Nano Letters. 2012 April 24; 12(5):2631-2638. Available from: https://pubs.acs.org/doi/10.1021/nl301104z DOI: 10.1021/nl301104z
5. Murray C, Kagan C, Bawendi M. Synthesis and Characterization of Monodisperse Nanocrystals and Close-Packed Nanocrystal Assemblies. Annual Review of Materials Science. 2000 August; 30(1):545-610. Available from: https://www.annualreviews.org/doi/10.1146/annurev.matsci.30.1.545 DOI: 10.1146/annurev.matsci.30.1.545

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Certified by Kagan, Cherie in SciENcv on 2024-09-06 15:53:25

Name: Kagan, Cherie

ORCID iD: https://orcid.org/0000-0001-6540-2009
Position Title: Professor
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. Defense Science Study Group, class of 2016-2017
2. Associate Editor, ACS Nano, 2013-2021
3. Elected to the Materials Research Society, Presidential Line, 2020-2022
4. World Economic Forum, Council on Emerging Technologies, 2013-2016
5. Department of Energy, Basic Energy Sciences, Materials Council, 2012-2015

IDENTIFYING INFORMATION:

NAME: Keske, Catherine

ORCID iD: https://orcid.org/0000-0002-8383-5630

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: University of California Merced, Merced, California, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Colorado State University, Fort Collins, CO, United States	PHD	08/2006	Agricultural and Resource Economics
Colorado School of Mines, Golden, Colorado, United States	PHD	05/2003	Mineral Economics
Vanderbilt University, Nashville, Tennessee, United States	MS	05/1994	Hearing and Speech Sciences
Bowling Green State University, Bowling Green, Ohio, United States	BS	05/1992	Communication Disorders

Appointments and Positions

2020 - present	Professor, University of California Merced, Merced, California, United States
2017 - 2020	Associate Professor, University of California-Merced, Merced, California, United States
2014 - 2017	Associate Professor, Memorial University of Newfoundland, Corner Brook, Newfoundland and Labrador, Canada
2012 - 2012	Associate Professor, Special Appointment, Colorado State University, Fort Collins, Colorado, United States
2011 - 2014	Research Associate, University of Colorado, Boulder, Colorado, United States
2008 - 2017	Adjunct Professor, University of Denver Sturm School of Law, Denver, Colorado, United States
2006 - 2012	Assistant Professor, Special Appointment, Colorado State University, Fort Collins, Colorado, United States

Products

Products Most Closely Related to the Proposed Project

1. Kagan CR., Arnold DP., Cappelleri DJ., Keske CM., Turner KT.. Special Report: The Internet of Things for Precision Agriculture (IoT4Ag). Computers and Electronics in Agriculture. 2022 May; 126(May 2022):106742. Available from: https://doi.org/10.1016/j.compag.2022.106742 DOI: https://doi.org/10.1016/j.compag.2022.106742
2. Yeo M, Nessledge A, Keske CM.. Understanding Technology Acceptance Disparity in Digital Agriculture. Table 4: Exploring Digital Spaces and Technologies, American Sociological

Association Proceedings. American Sociology Association Annual Meeting; 2024 August 09; Montreal, QC, Canada.

3. Keske CM.H., Arnold P, Cross JE., Bastian CT.. Does conservation ethic include intergenerational bequest? A random utility model analysis of conservation easements and agricultural landowners. Rural Sociology. 2021 February 03; 86(4):703. Available from: https://onlinelibrary.wiley.com/doi/10.1111/ruso.12370 DOI: https://doi.org/10.1111/ruso.12370
4. Nematian M, Keske C, Ng'ombe JN. A techno-economic analysis of biochar production and the bioeconomy for orchard biomass. Waste Manag. 2021 Nov;135:467-477. PubMed PMID: 34626931.
5. Nematian M, Ng'ombe JN., Keske C. Sustaining agricultural economies: regional economic impacts of biochar production from waste orchard biomass in California's Central Valley. Environment, Development and Sustainability. 2023 October 08. Available from: https://link.springer.com/article/10.1007/s10668-023-03984-6 DOI: https://doi.org/10.1007/s10668-023-03984-6

Other Significant Products, Whether or Not Related to the Proposed Project

1. Keske CM., Godfrey T, Hoag DL.K., Abedin J. . Economic feasibility of biochar and agriculture coproduction from Canadian black spruce forest. Food and Energy Security. 2020 February; 9(1):e188. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/fes3.202 DOI: http://dx.doi.org/10.1002/fes3.188
2. Hota SK., Hada SS., Keske CM., Diaz G. Feasibility of desalination by solar stills for small community scale freshwater demand. Journal of Cleaner Production. 2022 December 15; 379:134595. Available from: https://doi.org/10.1016/j.jclepro.2022.134595 DOI: https://doi.org/10.1016/j.jclepro.2022.134595
3. Field JL., Keske CM.H., Birch GL., Deport MW., Cotrufo M. Distributed bioenergy and biochar co-production: A regionally-specific case study of environmental benefits and economic impacts. Global Change Biology (GCB) Bioenergy. 2013 March 01; 5(2):177. Available from: https://doi.org/10.1111/gcbb.12032 DOI: https://doi.org/10.1111/gcbb.12032
4. Keske CM.H., Hoag DL., Brandess A, Johnson JJ.. Is it economically feasible for farmers to grow their own fuel? A study of Camelina sativa produced in the western United States as an on-farm biofuel. Biomass and Bioenergy. 2013 March 14; 54:89. Available from: http://dx.doi.org/10.1016/j.biombioe.2013.03.015 DOI: http://dx.doi.org/10.1016/j.biombioe.2013.03.015
5. Nyelele C, Keske C, Chung MG, Guo H, Egoh BN. Using social media data and machine learning to map recreational ecosystem services. Ecological Indicators. 2023 October 15; 154:110606. Available from: https://doi.org/10.1016/j.ecolind.2023.110606 DOI: https://doi.org/10.1016/j.ecolind.2023.110606

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Keske, Catherine in SciENcv on 2024-06-04 11:15:07

Catherine Keske Synergistic Activities

1) **Faculty and School of Engineering Executive Committee Chair, UC-Merced School of Engineering** (August 2020-December 2021; January 2018-August 2019). Responsible for reviewing and managing the School of Engineering curriculum and the shared governance process, as part of the UC-Merced Academic Senate. Responsible for initiating and instituting School policies, such as the School Laptop Policy. Provided leadership prior to the establishment of departments in 2018, and during COVID-19 pandemic in 2020-21 which involved instituting interim operating policies.

2) **IoT4Ag ERC DCI Pillar Co-Leader** (August 2020-February 2023). Jointly responsible for initiating and integrating DCI principles and activities throughout the IoT4Ag ERC, including triannual check-ins with students, guest speakers, and film screenings such as *Coded Bias* and *The Last Harvest*. Co-led initiatives such as the Pathway to the Ph.D. to expand participation of under-represented populations in engineering.

3) **UC-Merced Undergraduate Council** (August 2024-25; Vice Chair, August 2017-August 2019). Responsible for reviewing and approving campus undergraduate curriculum and academic policies related to undergraduate curriculum, and for reviewing student petitions. Co-led the establishment of the General Education Executive Committee in 2018, and served as an inaugural member, representing the School of Engineering (2018-2021).

4) **Course Development of "ENGR 156 Technical and Professional Writing for Scientists and Engineers"** (February-May 2024). Re-developed a writing course to prepare students to write professionally in their Engineering Capstone courses. Expanded the curriculum into a 4-hour course, and to instruct students on the use of AI in professional writing. Developed a writing seminar for the undergraduate student chapter of the Material Research Society.

5) **University of California System Board of Admissions and Relations with School (BOARS) Committee** (August 2018-August 2019). Responsible for reviewing academic policies for the University of California system, including admissions and standardized testing. Involved in deliberations leading to recommendations to discontinue standardized testing requirements for University of California system due to systemic bias.

IDENTIFYING INFORMATION:

NAME: Koppal, Sanjeev Jagannatha

ORCID iD: https://orcid.org/0000-0001-6769-8974

POSITION TITLE: Associate Professor

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Electrical and Computer Engineering, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Harvard University, Cambridge, Massachusetts, United States	Postdoctoral Fellow	09/2009 - 10/2012	Computer Vision
Carnegie Mellon University, Pittsburgh, PA, United States	Ph.D.	09/2009	Robotics
Carnegie Mellon University , Pittsburgh, PA, United States	MS	05/2006	Robotics
University of Southern California, Los Angeles, California, United States	BS	05/2003	Computer Science

Appointments and Positions

2014 - present	Associate Professor, University of Florida, Electrical and Computer Engineering, Gainesville, Florida, United States
2022 - present	Amazon Scholar, Amazon Robotics, Gainesville, Florida, United States
2014 - 2021	Assistant Professor, University of Florida, Gainesville, Florida, United States
2012 - 2014	Member of Technical Staff, Texas Instruments, Dallas, Texas, United States
2009 - 2012	Post-doctoral Research Associate, Harvard University, Cambridge, Massachusetts, United States
2003 - 2009	Research Assistant, Robotics Institute, Carnegie Mellon University, Pittsburgh, PA, United States
1999 - 2003	Undergraduate Research Assistant, Robotics Embedded Systems Lab, University of Southern California, Los Angeles, California, United States

Products

Products Most Closely Related to the Proposed Project

1. Liu X, Rego JD, Jayasuriya S, Koppal SJ. Event-based dual photography for transparent scene reconstruction. Opt Lett. 2023 Mar 1;48(5):1304–1307. PubMed PMID: 36857274.
2. Tilmon B, Jain E, Ferrari S, Koppal S. Fast Foveating Cameras for Dense Adaptive Resolution. IEEE Trans Pattern Anal Mach Intell. 2022 Sep;44(9):4867–4878. PubMed PMID: 33856979.
3. Liu X, Henderson K, Rego J, Jayasuriya S, Koppal S. Dense Lissajous sampling and interpolation for dynamic light-transport. Opt Express. 2021 Jun 7;29(12):18362–18381. PubMed PMID: 34154094.
4. Pittaluga F, Koppal SJ. Pre-Capture Privacy for Small Vision Sensors. IEEE Trans Pattern Anal

Mach Intell. 2017 Nov;39(11):2215–2226. PubMed PMID: 27959803.

5. Zhang X, Koppal SJ, Zhang R, Zhou L, Butler E, Xie H. Wide-angle structured light with a scanning MEMS mirror in liquid. Opt Express. 2016 Feb 22;24(4):3479–87. PubMed PMID: 26907006.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Koppal SJ, Narasimhan SG. Beyond perspective dual photography with illumination masks. IEEE Trans Image Process. 2015 Jul;24(7):2083–97. PubMed PMID: 25794389.
2. Holloway J, Mitra K, Koppal SJ, Veeraraghavan AN. Generalized assorted camera arrays: robust cross-channel registration and applications. IEEE Trans Image Process. 2015 Mar;24(3):823-35. PubMed PMID: 25532175.
3. Koppal SJ, Gkioulekas I, Young T, Park H, Crozier KB, Barrows GL, Zickler T. Toward wide-angle microvision sensors. IEEE Trans Pattern Anal Mach Intell. 2013 Dec;35(12):2982-96. PubMed PMID: 24136435.
4. Koppal SJ, Narasimhan SG. Appearance derivatives for isonormal clustering of scenes. IEEE Trans Pattern Anal Mach Intell. 2009 Aug;31(8):1375-85. PubMed PMID: 19542573.

Certification:

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Certified by Koppal, Sanjeev Jagannatha in SciENcv on 2024-06-27 17:23:01

Name: Koppal, Sanjeev J.
ORCID iD:
Position Title: Associate Professor
Primary Organization and Location: University of Florida

Synergistic Activities:

1. *Memberships:* IEEE (Institute of Electrical and Electronics Engineers), ACM (Association for Computing Machinery), OSA (Optical Society of America)
2. *Journal Reviewer:* (International Journal of Computer Vision (IJCV) 2006-present, Transactions on Pattern Analysis and Machine Intelligence (TPAMI) 2006-present
3. *Program Committee:* Computer Vision and Pattern Recognition (CVPR) 2006-present, International Conference on Computer Vision (ICCV) 2006-present, IEEE International Workshop on Projector-Camera Systems, 2010-present
4. *Service:* Area Chair CVPR 2019-20 and 2024, Posters chair for ICCP 2018, Co-Organizer for CCD 2018-19.

IDENTIFYING INFORMATION:

NAME: Krogmeier, James

POSITION TITLE: Associate Dean of Facilities and Planning

PRIMARY ORGANIZATION AND LOCATION: Purdue University College of Engineering, West Lafayette, Indiana, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Ecole Nationale Superior des Telecommunications, Paris, Not Applicable, N/A, France	Postdoctoral Fellow	03/1990 - 08/1990	Signal Processing
University of Illinois, Urbana, Illinois, United States	PHD	05/1990	Electrical Engineering
University of Illinois, Urbana, Illinois, United States	MS	08/1983	Electrical Engineering
University of Colorado, Boulder, Colorado, United States	BS	12/1981	Electrical Engineering

Appointments and Positions

2023 - present	Associate Dean of Facilities and Planning, Purdue University College of Engineering, West Lafayette, Indiana, United States
2020 - present	Professor of ECE, Purdue University, West Lafayette, IN, United States
2014 - 2020	Professor and Assoc. Head, ECE, Purdue University, West Lafayette, IN, United States
2013 - 2014	Professor of ECE, Purdue University, West Lafayette, IN, United States
1997 - 2012	Associate Professor, Purdue University, West Lafayette, IN, United States
1990 - 1997	Assistant Professor, Purdue University, West Lafayette, IN, United States
1984 - 1989	Research Assistant, University of Illinois, Urbana, IL, United States
1982 - 1984	Member of Technical Staff, AT&T Bell Laboratories, Whippany, NJ, United States

Products

Products Most Closely Related to the Proposed Project

1. Arakawa T, Goguri S, Krogmeier J, Kruger A, Love D, Mudumbai R, Swabey M. Optimizing Wireless Power Transfer From Multiple Transmit Coils. IEEE Access. 2018; 6:23828–23838. Available from: https://ieeexplore.ieee.org/document/8334813/ DOI: 10.1109/ACCESS.2018.2825290
2. Chou T, Michelusi N, Love D, Krogmeier J. Fast Position-Aided MIMO Beam Training via Noisy Tensor Completion. IEEE Journal of Selected Topics in Signal Processing. 2021; 15(3):774-788. Available from: https://ieeexplore.ieee.org/document/9369831/ DOI: 10.1109/JSTSP.2021.3063837
3. Zhang Y, Anderson C, Michelusi N, Love D, Baker K, Krogmeier J. Propagation Modeling Through Foliage in a Coniferous Forest at 28 GHz. IEEE Wireless Communications Letters.

2019; 8(3):901-904. Available from: https://ieeexplore.ieee.org/document/8641450/ DOI: 10.1109/LWC.2019.2899299

4. Hur S, Kim T, Love D, Krogmeier J, Thomas T, Ghosh A. Millimeter Wave Beamforming for Wireless Backhaul and Access in Small Cell Networks. IEEE Transactions on Communications. 2013 October; 61(10):4391-4403. Available from: http://ieeexplore.ieee.org/document/6600706/ DOI: 10.1109/TCOMM.2013.090513.120848
5. Marcum A, Krogmeier J, Love D, Sprintson A. Analysis and Implementation of Asynchronous Physical Layer Network Coding. IEEE Transactions on Wireless Communications. 2015 December; 14(12):6595-6607. Available from: http://ieeexplore.ieee.org/document/7159066/ DOI: 10.1109/TWC.2015.2456898

Other Significant Products, Whether or Not Related to the Proposed Project

1. Duly A, Kim T, Love D, Krogmeier J. Closed-Loop Beam Alignment for Massive MIMO Channel Estimation. IEEE Communications Letters. 2014; 18(8):1439-1442. Available from: https://ieeexplore.ieee.org/document/6784322/ DOI: 10.1109/LCOMM.2014.2316157
2. Vanjari S, Krogmeier J, Bell M. Remote data sensing using SAR and harmonic reradiators. IEEE Transactions on Aerospace and Electronic Systems. 2007 October; 43(4):1426-1440. Available from: http://ieeexplore.ieee.org/document/4441749/ DOI: 10.1109/TAES.2007.4441749
3. Duly A, Love D, Krogmeier J. Time-Division Beamforming for MIMO Radar Waveform Design. IEEE Transactions on Aerospace and Electronic Systems. 2013 April; 49(2):1210-1223. Available from: http://ieeexplore.ieee.org/document/6494408/ DOI: 10.1109/TAES.2013.6494408
4. Ernst J, Krogmeier J, Bullock D. Maximum-Likelihood Acceleration Estimation From Existing Roadway Vehicle Detectors. IEEE Transactions on Intelligent Transportation Systems. 2012 June; 13(2):759-769. Available from: http://ieeexplore.ieee.org/document/6145681/ DOI: 10.1109/TITS.2011.2181947
5. Pande T, Love D, Krogmeier J. Reduced Feedback MIMO-OFDM Precoding and Antenna Selection. IEEE Transactions on Signal Processing. 2007 May; 55(5):2284-2293. Available from: http://ieeexplore.ieee.org/document/4160202/ DOI: 10.1109/TSP.2006.890936

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Certified by Krogmeier, James in SciENcv on 2024-07-05 16:01:54

Synergistic Activities

James V. Krogmeier

Purdue University

1. Open Ag Technology and Systems Center (OATS): Co-lead an industry and academic consortium for open source technologies in agriculture (OATS) which features an open source cloud-to-cloud API to enable interoperability of farmer-industry-university cloud data systems to magnify the impact of agricultural research.
2. Developer of the following courses at Purdue University: 1) ECE 595Z (Real-Time Digital Signal Processing with Applications), 2) ECE 495M (Projects in Mobile Communications), 3) ECE 495W (The Wireless Revolution), and ECE 495 TUV (Vertically Integrated Projects). Extensive experience advising teams of undergraduate students working on team-based research through Vertically Integrated Projects (VIP)
3. Co-advised teams in the DARPA Spectrum Challenge and DARPA Spectrum Collaboration Challenge (SC2)
4. Member of the Purdue team participating in the NSF Platforms for Advanced Wireless Research (PAWR) testbed Aerial Experimentation and Research Platform for Advanced Wireless (AERPAW). AERPAW is led by NC State University.
5. Past Associate Editor for the IEEE Transactions on Intelligent Transportation Systems (2013-2016), the IEEE Transactions on Wireless Communications (2001-2003), the IEEE Journal on Selected Areas in Communications (2000-2001).

IDENTIFYING INFORMATION:

NAME: Kumar, Vijay

ORCID iD: https://orcid.org/0000-0002-3902-9391

POSITION TITLE: Professor and Nemirovsky Family Dean of Penn Engineering

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Ohio State University, Columbus, Ohio, USA	PHD	07/1987	Mechanical Engineering
Ohio State University, Columbus, Ohio, USA	MS	12/1984	Mechanical Engineering
Indian Institute of Technology, Kanpur, Uttar Pradesh, USA	BME	05/1983	Mechanical Engineering

Appointments and Positions

1987 - present	Professor and Nemirovsky Family Dean of Penn Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2015 - present	Nemirovsky Family Dean, School of Engineering and Applied Science, University of Pennsylvania, Philadelphia, PA, USA
2014 - present	Founder and Chief Scientific Officer, Exyn Technologies, Philadelphia, PA, USA
1998 - present	Professor, University of Pennsylvania, School of Engineering and Applied Science, Philadelphia, PA, USA
2012 - 2014	Assistant Director of Robotics and Cyberphysical Systems, White House Office of Science and Technology Policy, Washington, DC, USA
1998 - 2005	Director, GRASP Laboratory, School of Engineering and Applied Science, University of Pennsylvania, Philadelphia, PA, 19104
1993 - 1998	Associate Professor, School of Engineering and Applied Science, University of Pennsylvania, Philadelphia, PA, USA
1987 - 1993	Assistant Professor, School of Engineering and Applied Science, University of Pennsylvania, Philadelphia, PA, USA

Products

Products Most Closely Related to the Proposed Project

1. Liu X, Chen S, Liu C, Shivakumar S, Das J, Taylor C, Underwood J, Kumar V. Monocular Camera Based Fruit Counting and Mapping With Semantic Data Association. IEEE Robotics and Automation Letters. 2019; 4(3):2296-2303. Available from: https://ieeexplore.ieee.org/document/8653965/ DOI: 10.1109/LRA.2019.2901987
2. Liu Xu, Chen Steven W, Aditya Shreyas, Sivakumar Nivedha, Dcunha Sandeep, Qu Chao, Taylor Camillo J, Das Jnaneshwar, Kumar Vijay. Robust fruit counting: Combining deep

learning, tracking, and structure from motion. 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS); 2018; c2018.

3. Paulos James, Chen Steven W, Shishika Daigo, Kumar Vijay. Decentralization of multiagent policies by learning what to communicate. 2019 International Conference on Robotics and Automation (ICRA); 2019; c2019.
4. Sun Ke, Mohta Kartik, Pfrommer Bernd, Watterson Michael, Liu Sikang, Mulgaonkar Yash, Taylor Camillo J, Kumar Vijay. Robust stereo visual inertial odometry for fast autonomous flight. IEEE Robotics and Automation Letters. 2018; 3(2):965--972.
5. Tolstaya Ekaterina, Gama Fernando, Paulos James, Pappas George, Kumar Vijay, Ribeiro Alejandro. Learning decentralized controllers for robot swarms with graph neural networks. Conference on Robot Learning; 2020; c2020.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Ayanian Nora, Kumar Vijay. Decentralized feedback controllers for multiagent teams in environments with obstacles. IEEE Transactions on Robotics. 2010; 26(5):878--887.
2. Belta Calin, Kumar Vijay. Abstraction and control for groups of robots. IEEE Transactions on robotics. 2004; 20(5):865--875.
3. Berman Spring, Hal\'asz \'Ad\'am, Hsieh M Ani, Kumar Vijay. Optimized stochastic policies for task allocation in swarms of robots. IEEE Transactions on Robotics. 2009; 25(4):927--937.
4. Das Aveek, Fierro Rafael, Kumar Vijay, Ostrowski Jim, Spletzer John, Taylor Camillo. A framework for vision based formation control. IEEE Transactions on Robotics and Automation. 2002; 18(5):813--825.
5. Mellinger Daniel, Kumar Vijay. Minimum snap trajectory generation and control for quadrotors. 2011 IEEE international conference on robotics and automation; 2011; c2011.

Certification:

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Certified by Kumar, Vijay in SciENcv on 2024-07-17 06:31:02

Synergistic Activities

R. Vijay Kumar

Nemirovsky Family Dean of Penn Engineering.

Professor, Departments of Mechanical Engineering and Applied Mechanics, Computer and Information Science, and Electrical and Systems Engineering.

1. Former director of the GRASP Laboratory (1998-2005), and founder of the GRASP Outreach

Program and Summer Robotics course (2006) now impacting over 800 K-12 students every year

2. Organizer of several conferences currently General Co-Chair, International Conference on Robotics and Automation, 2022.

3. Elected and active member of the multiple societies, including National Academy of Engineering, American Philosophical Society, and American Academy of Arts and Sciences.

4. Key roles in shaping the National Robotics Initiative, including service to the OSTP, White House (2012-14).

5. Founder and Scientific Advisor of Exyn Technologies creating autonomous flying robots operating in underground mines and construction sites

IDENTIFYING INFORMATION:

NAME: Love, David

POSITION TITLE: Nick Trbovich Professor of ECE

PRIMARY ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
The University of Texas at Austin, Austin, Texas, United States	PHD	05/2004	Electrical Engineering
The University of Texas at Austin, Austin, Texas, United States	MS	05/2002	Electrical Engineering
The University of Texas at Austin, Austin, Texas, United States	BS	12/2000	Electrical Engineering

Appointments and Positions

2018 - present	Nick Trbovich Professor of ECE, Purdue University, West Lafayette, Indiana, United States
2013 - present	Consultant, Texas Instruments, Dallas, Texas, United States
2013 - present	Professor, Purdue University, West Lafayette, Indiana, United States
2018 - 2018	Reilly Professor of ECE, Purdue University, West Lafayette, Indiana, United States
2009 - 2013	Associate Professor, Purdue University, West Lafayette, Indiana, United States
2004 - 2009	Assistant Professor, Purdue University, West Lafayette, Indiana, United States
2002 - 2002	Summer Co-Op, Texas Instruments, Dallas, Texas, United States
2000 - 2000	Summer Co-Op, Texas Instruments, Dallas, Texas, United States

Products

Products Most Closely Related to the Proposed Project

1. Hur S, Kim T, Love DJ, Krogmeier JV, Thomas TA, Ghosh A. Millimeter Wave Beamforming for Wireless Backhaul and Access in Small Cell Networks. IEEE Transactions on Communications. 2013 October.
2. Zhang J, Björnson E, Matthaiou M, Ng DW, Yang H, Love DJ. Prospective Multiple Antenna Technologies for Beyond 5G. IEEE Journal on Selected Areas in Communications. 2022 August.
3. Hosseinalipour S, Azam SS, Brinton CG, Michelusi N, Aggarwal V, Love DJ, Dai H. Multi-stage hybrid federated learning over large-scale D2D-enabled fog networks. IEEE/ACM Transactions on Networking. 2022 August.
4. Zhang Y, Love DJ, Krogmeier JV, Anderson CR, Heath RW, Buckmaster DR. Challenges and Opportunities of Future Rural Wireless Communications. IEEE Communications Magazine. 2021 December.
5. Zhang Y, Anderson CR, Michelusi N, Love DJ, Baker KR, Krogmeier JV. Propagation

Modeling Through Foliage in a Coniferous Forest at 28 GHz. IEEE Wireless Communications Letters. 2019 June.

Other Significant Products, Whether or Not Related to the Proposed Project

1. Suresh V, Ruzomberka E, Wang C, Love DJ. Causal Adversarial Channels With Feedback Snooping,. IEEE Transactions on Information Theory. 2022 March.
2. Ogbe D, Love DJ, Rebholz M, Bidigare T. Efficient Channel Estimation for Aerial Wireless Communications. IEEE Transactions on Aerospace and Electronic Systems. 2019 December.
3. Shin W, Vaezi M, Lee B, Love DJ, Lee J, Poor H. Non-Orthogonal Multiple Access in Multi-Cell Networks: Theory, Performance, and Practical Challenges. IEEE Communications Magazine. 2017 October.
4. Love DJ, Heath RW, Strohmer T. Grassmannian Beamforming for Multiple-Input Multiple-Output Wireless Systems. IEEE Transactions on Information Theory. 2003 October.
5. Choi J, Love DJ, Bidigare P. Downlink Training Techniques for FDD Massive MIMO Systems: Open-Loop and Closed-Loop Training With Memory. IEEE Journal of Selected Topics in Signal Processing. 2014 October.

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Love, David in SciENcv on 2024-07-03 22:47:49

Synergistic Activities

David J. Love

Purdue University

1. Served on the Executive Committee of the National Spectrum Consortium (NSC) in 2019-2021
2. Hold 32 issued US patents.
3. Extensive experience advising teams of undergraduate students working on team-based research through Vertically Integrated Projects (VIP)
4. Co-advised teams in the DARPA Spectrum Challenge and DARPA Spectrum Collaboration Challenge (SC2)
5. Member of the Purdue team participating in the NSF Platforms for Advanced Wireless Research (PAWR) testbed Aerial Experimentation and Research Platform for Advanced Wireless (AERPAW). AERPAW is led by NC State University.

IDENTIFYING INFORMATION:

NAME: Messina, Carlos

ORCID iD: https://orcid.org/0000-0002-5501-9281

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Florida, Gainesville, Florida, United States	PHD	12/2003	Agricultural & Biological Engineering
University of Buenos Aires, Buenos Aires, Not Applicable, N/A, Argentina	MS	07/1999	Crop Physiology
University of Buenos Aires, Buenos Aires, Not Applicable, N/A, Argentina	BS	12/1995	Agronomy & Crop Science

Appointments and Positions

2022 - present Professor, University of Florida, Gainesville, Florida, United States
2019 - 2021 Distinguished Laureate, Corteva Agriscience, Johnston, Iowa, United States
2014 - 2018 Senior Scientist, DuPont Pioneer, Johnston, Iowa, United States
2006 - 2013 Research Scientist, DuPont Pioneer, Johnston, Iowa, United States
2004 - 2006 Senior Research Associate, DuPont Pioneer, Johnston, Iowa, United States

Products

Products Most Closely Related to the Proposed Project

1. Messina CD, Gho C, Hammer GL, Tang T, Cooper M. Two decades of harnessing standing genetic variation for physiological traits to improve drought tolerance in maize. J Exp Bot. 2023 Sep 2;74(16):4847–4861. PubMed Central PMCID: PMC10474595.
2. Messina C, Van Eeuwijk F, Tang T, Truong S, McCormick R, Technow F, Powell O, Mayor L, Gutterson N, Jones J. Crop improvement for circular bioeconomy systems. Journal of the ASABE. 2022; 65(3):491-504.
3. McCormick R, Truong S, Rotundo J, Gaspar A, Kyle D, van Eeuwijk F, Messina C. Intercontinental prediction of soybean phenology via hybrid ensemble of knowledge-based and data-driven models. in silico Plants. 2021; 3(1):diab004. issn: 2517-5025
4. Peng B, Guan K, Tang J, Ainsworth EA, Asseng S, Bernacchi CJ, Cooper M, Delucia EH, Elliott JW, Ewert F, Grant RF, Gustafson DI, Hammer GL, Jin Z, Jones JW, Kimm H, Lawrence DM, Li Y, Lombardozzi DL, Marshall-Colon A, Messina CD, Ort DR, Schnable JC, Vallejos CE, Wu A, Yin X, Zhou W. Towards a multiscale crop modelling framework for climate change adaptation assessment. Nat Plants. 2020 Apr;6(4):338-348. PubMed PMID: 32296143.
5. Rotundo J, Rech R, Cardoso M, Fang Y, Tang T, Olson N, Pyrik B, Conrad G, Borras L,

Mihura E. Development of a decision-making application for optimum soybean and maize fertilization strategies in Mato Grosso. Computers and Electronics in Agriculture. 2022; 193:106659. issn: 0168-1699

Other Significant Products, Whether or Not Related to the Proposed Project

1. Wu A, Truong SH, McCormick R, van Oosterom EJ, Messina CD, Cooper M, Hammer GL. Contrasting leaf-scale photosynthetic low-light response and its temperature dependency are key to differences in crop-scale radiation use efficiency. New Phytol. 2024 Mar;241(6):2435-2447. PubMed PMID: 38214462.
2. Messina C, Rotundo J, Hammer G, Gho C, Reyes A, Fang Y, van Oosterom E, Borras L, Cooper M. Radiation use efficiency increased over a century of maize (Zea mays L.) breeding in the US corn belt. Journal of Experimental Botany. 2022; 73(16):5503–5513. issn: 0022-0957
3. Messina C, McDonald D, Poffenbarger H, Clark R, Salinas A, Fang Y, Gho C, Tang T, Graham G, Hammer GL, Cooper M. Reproductive resilience but not root architecture underpins yield improvement under drought in maize. J Exp Bot. 2021 Jul 10;72(14):5235-5245. PubMed Central PMCID: PMC8272564.
4. Reynolds M, Atkin OK, Bennett M, Cooper M, Dodd IC, Foulkes MJ, Frohberg C, Hammer G, Henderson IR, Huang B, Korzun V, McCouch SR, Messina CD, Pogson BJ, Slafer GA, Taylor NL, Wittich PE. Addressing Research Bottlenecks to Crop Productivity. Trends Plant Sci. 2021 Jun;26(6):607–630. PubMed PMID: 33893046.
5. Lobell D, Hammer G, McLean G, Messina C, Roberts M, Schlenker W. The critical role of extreme heat for maize production in the United States. Nature climate change. 2013; 3(5):497–501. issn: 1758–678X

Certification:

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I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729–3733 and 3802.

Certified by Messina, Carlos in SciENcv on 2024-08-22 08:43:25

Synergistic Activities

Messina Charlie, PhD
Professor, Department of Horticultural Sciences
Director UF/IFAS Crop Transformation Center
University of Florida

1. Training women in STEM and leadership – mentoring female scientists (5 PhD ,one NSF GRFP, one UF-PBWG scholar; 1 MSc; 1 postdoc) and undergraduates (2, 1 UF/CALS scholar intern, 1 Brain Health Initiative intern).

2. Broadening Participation of Underrepresented Minorities in STEM – training and mentoring one Hispanic PhD doctoral student.

3. Reviewer/project contributor/editorial board: Department of Energy, National Science Foundation, United States Department of Agriculture, Office of Science and Technology Policy-The White House, John Deere, In-Silico Plant, The Plant Genome

4. Chair/co-chair of conferences and workshops: Urban Agriculture (2024, Sarasota, FL), Farming systems (Chicago, IL, 2024), Genotype x Environment x Management interactions (2022, Brisbane, AU; 2023, Gainesville, US; 2024, Wageningen, NL), Circular Bioeconomy Day (2023), Interdrought VIII (2025, La Serena, Chile)

IDENTIFYING INFORMATION:

NAME: Olsson, Roy H.

POSITION TITLE: Associate Professor

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Dept. of Electrical and Systems Engineering, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Michigan, Ann Arbor, Michigan, United States	PHD	06/2004	Electrical Engineering
University of Michigan, Ann Arbor, Michigan, United States	MS	12/2001	Electrical Engineering
West Virginia University, Morgantown, West Virginia, United States	BS	05/1999	Electrical Engineering and Computer Engineering

Appointments and Positions

2022 - present	Associate Professor, University of Pennsylvania, Dept. of Electrical and Systems Engineering, Philadelphia, Pennsylvania, United States
2019 - 2022	Assistant Professor, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2014 - 2019	Program Manager, Defense Advanced Research Projects Agency, Microsystems Technology Office, Arlington, Virginia, United States
2004 - 2014	Principal Member of the Technical Staff, Sandia National Laboratories, Microelectromechanical Systems (MEMS) Department, Albuquerque, New Mexico, United States

Products

Products Most Closely Related to the Proposed Project

1. Wang D, Zheng J, Musavigharavi P, Zhu W, Foucher AC, Trolier-McKinstry SE, Stach EA, Olsson RH. Ferroelectric Switching in Sub-20 nm Aluminum Scandium Nitride Thin Films. IEEE Electron Device Letters. 2020 December; 41(12):1774-1777. DOI: 10.1109/LED.2020.3034576
2. Wang D, Musavigharavi P, Zheng J, Esteves G, Liu X, Fiagbenu MMA, Stach EA, Jariwala D, Olsson III RH. Sub-Microsecond Polarization Switching in (Al,Sc)N Ferroelectric Capacitors Grown on Complementary Metal–Oxide–Semiconductor-Compatible Aluminum Electrodes. Physica Status-Solidi (RRL) – Rapid Research Letters. 2021 February; 15(2000575):1-6. DOI: https://doi.org/10.1002/pssr.202000575
3. Wojciechowski KE, Baker MS, Clews PJ, Olsson RH. A Fully Integrated Oven Controlled Microelectromechanical Oscillator—Part I: Design and Fabrication. IEEE Journal of Microelectromechanical Systems. 2015 December; 24(6):1782-1794. DOI: 10.1109/JMEMS.2015.2441037

4. Liu X, Wang D, Kim KH, Katti K, Zheng J, Musavigharavi P, Miao J, Stach EA, Olsson RH 3rd, Jariwala D. Post-CMOS Compatible Aluminum Scandium Nitride/2D Channel Ferroelectric Field-Effect-Transistor Memory. Nano Lett. 2021 May 12;21(9):3753-3761. PubMed PMID: 33881884.
5. Liu X, Zheng J, Wang D, Musavigharavi P, Stach EA, Olsson III RH, Jariwala D. Aluminum Scandium Nitride based Metal-Ferroelectric-Metal Diode Memory Devices with High On/Off Ratios. Applied Physics Letters. 2021 May; 118(202901). DOI: 10.1063/5.0051940

Other Significant Products, Whether or Not Related to the Proposed Project

1. Olsson III RH, El-Kady I. Microfabricated Phononic Crystal Devices and Applications. Measurement Science and Technology. 2008 November 13; 20(1):012002. DOI: 10.1088/0957-0233/20/1/012002
2. Olsson RH, Wise KD. A Three-Dimensional Neural Recording Microsystem with Implantable Data Compression Circuitry. IEEE Journal of Solid-State Circuits. 2005 December; 40(12):2796-2804.
3. Olsson RH, Hattar K, Homeijer SJ, Wiwi M, Eichenfield M, Branch DW, Baker MS, Nguyen J, Clark B, Bauer T, Friedmann TA. A High Electromechanical Coupling Coefficient SH0 Lamb Wave Lithium Niobate Micromechanical Resonator and a Method for Fabrication. Sensors and Actuators A: Physical. 2014 March; 209:183-190. DOI: 10.1016/j.sna.2014.01.033
4. Piazza G, Felmetsger V, Muralt P, Olsson RH, Ruby R. Piezoelectric Aluminum Nitride Films for Microelectromechanical Systems. MRS Bulletin. 2012 November 01; 37:1051–1061. DOI: 10.1557/mrs.2012.268

Certification:

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Certified by Olsson, Roy H. in SciENcv on 2024-07-25 10:47:30

Name: Roy Olsson

ORCID iD: 0000-0002-8007-5082
Position Title: Associate Professor
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. TC-6 RF MEMS and Microwave Acoustics Committee Member, IEEE Microwave Theory and Techniques Society, 2022-Present
2. TPC Member (Power, Microwave/mm-wave and Analog Devices/Systems), *IEEE International Electronic Devices Meeting (IEDM),* 2023-2024
3. General Chair for the 9th PiezoMEMS Workshop, August 2022

IDENTIFYING INFORMATION:

NAME: Quinn, Daniel

POSITION TITLE: Assistant Professor

PRIMARY ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Kentucky, Lexington, Kentucky, United States	PHD	05/2021	Plant and Soil Science
Michigan State University, East Lansing, Michigan, United States	MS	05/2018	Crop and Soil Science
Michigan State University, East Lansing, Michigan, United States	BS	12/2015	Crop and Soil Science

Appointments and Positions

2021 - present Assistant Professor, Purdue University, West Lafayette, Indiana, United States

Products

Products Most Closely Related to the Proposed Project

1. Quinn D, Poffenbarger H, Miguez F, Lee C. Corn optimum nitrogen fertilizer rate and application timing when following a rye cover crop. Field Crops Research. 2023; 291:108794. issn: 0378-4290
2. Laurent A, Cleveringa A, Fey S, Kyveryga P, Wiese N, Lefebvre M, Newville D, Quinn D, McGuire J, Tao H. Late-season corn stalk nitrate measurements across the US Midwest from 2006 to 2018. Scientific Data. 2023; 10(1):192. issn: 2052-4463
3. Quinn D, Poffenbarger H, Leuthold S, Lee C. Corn response to in-furrow fertilizer and fungicide across rye cover crop termination timings. Agronomy Journal. 2021.
4. Quinn D, Lee C, Poffenbarger H. Corn yield response to sub-surface banded starter fertilizer in the US: A meta-analysis. Field Crops Research. 2020; 254:107834. issn: 0378-4290

Other Significant Products, Whether or Not Related to the Proposed Project

Certification:

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Certified by Quinn, DanIel in SciENcv on 2024-07-01 11:26:17

Synergistic Activities

Name: Daniel Quinn

Institution: Purdue University

Extension and Outreach Professional: served as a lead extension and outreach specialist for corn agronomic information across Indiana and the Midwest. Activities and contributions have included newsletter articles, media interviews, field days, and workshops. Dr. Quinn has given >120 invited presentations to >12,000 people across 5 states and 4 countries in the 3 years within his current position. In addition, Dr. Quinn has contributed to >70 news interviews, news releases, >50 podcasts, 20 television and rate interviews and >50 newsletter articles. These activities provide direct information and education to stakeholders, agriculture professionals, federal employees, and students across Indiana and the Midwest.

Associate Editor: currently serves as an Associate Editor for the journal Agrosystems, Geosciences, and Environment. This journal is an open access journal which publishes studies that focus on research including all aspects of agriculture, plant, environmental, and soil science.

Field Research Professional: currently leads an applied field research program which includes the design and implementations of 50+ field research trials coordinated with industry, research, and farm personnel. Research data and reports generated from these research trials are nationally recognized and are shared via the "Applied Research for Indiana Corn Production" annual research book which is shared across Indiana, the Midwest and the entire U.S.

Journal Reviewer: currently serves as a manuscript reviewer for multiple national and international agriculture, crop science, and soil science journals.

IDENTIFYING INFORMATION:

NAME: Ribeiro, Alejandro

POSITION TITLE: Professor of Electrical & Systems Engineering

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Minnesota, Twin Cities, Minnesota, United States	Ph. D.	12/2006	Electrical & Computer Engineering
University of Minnesota, Twin Cities, Minnesota, United States	M. Sc.	09/2005	Electrical & Computer Engineering
Universidad de la República Oriental del Uruguay, Montevideo, Not Applicable, N/A, Uruguay	B. Sc.	12/1998	Electrical Engineering

Appointments and Positions

2018 - present	Professor of Electrical & Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2014 - 2018	Rosenbluth Associate Professor, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2008 - 2014	Assistant Professor, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2006 - 2008	Research Associate, University of Minnesota, Twin Cities, Minnesota, United States
2003 - 2006	Research Assistant, University of Minnesota, Twin Cities, Minnesota, United States
1998 - 2003	Systems Engineer, Bellsouth, Montevideo, Not Applicable, N/A, Uruguay

Products

Products Most Closely Related to the Proposed Project

1. Gama F, Marques AG, Leus G, Ribeiro A. Convolutional Neural Network Architectures for Signals Supported on Graphs. IEEE Transactions on Signal Processing. 2019 February 15; 67(4):1034 - 1049. Available from: https://ieeexplore.ieee.org/document/8579589
2. Gama F, Ribeiro A, Bruna J. Diffusion Scattering Transforms on Graphs. The International Conference on Learning Representations. 2019 May 06. Available from: arXiv:1806.08829
3. Huang W, Marques AG, Ribeiro A. Rating prediction via graph signal processing. IEEE Transactions on Signal Processing. 2018 October 01; 66(19):5066 - 5081. Available from: https://ieeexplore.ieee.org/document/8430557
4. Marques AG, Segarra S, Leus G, Ribeiro A. Stationary Graph Processes and Spectral Estimation. IEEE Transactions on Signal Processing. 2017 November 15; 65(22):5911 - 5926. Available from: https://ieeexplore.ieee.org/document/8008816

5. Marques AG, Segarra S, Leus G, Ribeiro A. Sampling of Graph Signals with Successive Local Aggregations. IEEE Transactions on Signal Processing. 2016 April; 64(7):1832 - 1843. Available from: https://ieeexplore.ieee.org/document/7352352

Other Significant Products, Whether or Not Related to the Proposed Project

1. Gama F, Ribeiro A. Ergodicity in Stationary Graph Processes: A Weak Law of Large Numbers. IEEE Transactions on Signal Processing. 2019 May 15; 67(10):2761 – 2774. Available from: https://ieeexplore.ieee.org/abstract/document/8680679
2. Chamon LFO, Ribeiro A. Greedy sampling of graph signals. IEEE Transactions on Signal Processing. 2018 January 01; 66(1):34 - 47. Available from: https://ieeexplore.ieee.org/document/8047995
3. Segarra S, Marques AG, Mateos G, Ribeiro A. Network Topology Inference from Spectral Templates. IEEE Transactions on Signal and Information Processing over Networks. 2017 September; 3(3):467 – 483. Available from: https://ieeexplore.ieee.org/document/7990048
4. Segarra S, Marques AG, Ribeiro A. Optimal Graph-Filter Design and Applications to Distributed Linear Network Operators. IEEE Transactions on Signal Processing. 2017 August 01; 65(15):4117 - 4131. Available from: https://ieeexplore.ieee.org/document/7926424
5. Huang W, Goldsberry L, Wymbs NF, Grafton ST, Bassett DS, Ribeiro A. Graph frequency analysis of brain signals. IEEE Journal of Selected Topics in Signal Processing. 2016 October; 10(7):1189 - 1203. Available from: https://ieeexplore.ieee.org/document/7544580

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Certified by Ribeiro, Alejandro in SciENcv on 2024-07-31 10:37:59

Name: Alejandro Ribeiro
ORCID iD: 0000-0002-0312-8857
Position Title: Solomon & Sylvia G. Charp Professor of Electrical Engineering
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. Learning for Dynamics and Control Conference Learning under Requirements: Supervised and Reinforcement Learning with Constraints. July 15-27, 2024. 2.
2. AAAI Conference on Artificial Intelligence Learning under Requirements: Supervised and Reinforcement Learning with Constraints. February 20-27, 2024. 3.
3. IEEE International Conference on Acoustics, Speech and Signal Processing. Short Course on Graph Neural Networks. June 6-9, 2023.
4. Workshop on Resource-Constrained Learning in Wireless Networks at the Conference on Machine Learning and Systems. Plenary. Autonomous Wireless Communication Networks. June 8, 2023.
5. Khipu: Latin American Meeting In Artificial Intelligence. Keynote. Graph Neural Networks. March 7, 2023.

IDENTIFYING INFORMATION:

NAME: Sharma, Vivek

ORCID iD: https://orcid.org/0000-0002-8092-4355

POSITION TITLE: Assistant Professor, Precision Water Management Specialist

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Nebraska, Lincoln, Lincoln, Nebraska, United States	DENG	05/2015	Biological Systems Engineering
University of Nebraska, Lincoln, Lincoln, Nebraska, USA	MENG	05/2011	Biological Systems Engineering
College of Agricultural Engineering, Punjab Agricultural University, Ludhiana, Punjab, India	BENG	05/2008	Agricultural Engineering

Appointments and Positions

2020 - present Assistant Professor, Precision Water Management Specialist, University of Florida, Gainesville, Florida, United States

2016 - 2019 Assistant Professor, Irrigation Specialist, University of Wyoming, Powell, WY, United States

2015 - 2016 Post-Doctoral Research Associate, University of Nebraska Lincoln, Lincoln, NE, United States

2009 - 2015 Graduate Research Assistant, University of Nebraska Lincoln, Lincoln, NE, United States

2008 - 2009 Assistant Manager, CLAAS India Ltd., Faridabad, Not Applicable, N/A, India

Products

Products Most Closely Related to the Proposed Project

1. Dhillon R, Takoo G, Sharma V, Nagle M. Utilizing Machine Learning Framework to Evaluate the Effect of Climate Change on Maize and Soybean Yield. Computers and Electronics in Agriculture. 2024 June; 221:108982–. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0168169924003739 DOI: 10.1016/j.compag.2024.108982
2. Sharma V, Rai A. Dry Bean (*Phaseolus vulgaris* L.) Crop Water Production Functions and Yield Response Factors in an Arid to Semi-Arid Climate. Journal of the ASABE. 2022; 65(1):51–65. Available from: https://elibrary.asabe.org/abstract.asp?AID=52997&t=3&dabs=Y&redir=&redirType= DOI: 10.13031/ja.14582
3. Das S, Kaur S, Sharma V. Determination of threshold crop water stress index for sub-surface

drip irrigated maize–wheat cropping sequence in semi–arid region of Punjab. Agricultural Water Management. 2024 August; 301:108957-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0378377424002920 DOI: 10.1016/j.agwat.2024.108957

4. Acharya B, Sharma V. Comparison of Satellite Driven Surface Energy Balance Models in Estimating Crop Evapotranspiration in Semi-Arid to Arid Inter-Mountain Region. Remote Sensing. 2021 May 07; 13(9):1822-. Available from: https://www.mdpi.com/2072-4292/13/9/1822 DOI: 10.3390/rs13091822
5. Acharya B, Sharma V, Heitholt J, Tekiela D, Nippgen F. Quantification and Mapping of Satellite Driven Surface Energy Balance Fluxes in Semi-Arid to Arid Inter-Mountain Region. Remote Sensing. 2020 December 08; 12(24):4019-. Available from: https://www.mdpi.com/2072-4292/12/24/4019 DOI: 10.3390/rs12244019

Other Significant Products, Whether or Not Related to the Proposed Project

1. Potential Benefits of Water–Use Efficiency Technologies in Southeastern Wyoming. Journal of the ASFMRA. 2024 February.
2. Morrow M, Sharma V, Hochmuth R, Barrett C, Burani-Arouca M. Carrot (Daucus carota) Production in the Sandy Soils of North Florida: Nitrogen Fertilization Guidelines. EDIS. 2023 August 09; 2023(4):-. Available from: https://journals.flvc.org/edis/article/view/132799 DOI: 10.32473/edis-ae588-2023
3. Acharya B, Sharma V, Barrett C, Sidhu S, Zotarelli L, Dukes M. Methods to Quantify In-Field Nutrient Leaching. EDIS. 2023 January 11; 2022(6):-. Available from: https://journals.flvc.org/edis/article/view/131546 DOI: 10.32473/edis-ae581-2022

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Certified by Sharma, Vivek in SciENcv on 2024-08-27 16:04:05

Name: Sharma, Vivek
ORCID iD: 0000-0002-8092-4355
Position Title: Ast. Professor
Primary Organization and Location: University of Florida, Gainesville, FL.

Synergistic Activities:

1. Associate Editor (AE) for ASABE and the NRES Community
2. Associate Editor (AE) for Journal of Irrigation and Drainage Engineering
3. Chair, ASABE NRES-24 Irrigation group.
4. Chair, Florida Section, ASABE conference.
5. Leader, Florida Statewide Agricultural Soil Moisture Network

IDENTIFYING INFORMATION:

NAME: Small, Ian

ORCID iD: https://orcid.org/0000-0001-5406-3486

POSITION TITLE: Associate Professor

PRIMARY ORGANIZATION AND LOCATION: University of Florida, North Florida Research & Education Center, Quincy, FL, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Cornell University, Ithaca, NY, US	Ph.D.	05/2016	Dept. Plant Pathology & Plant-Microbe Biology
Stellenbosch University, Stellenbosch, Not Applicable, N/A, South Africa	M.Sc.	01/2010	Dept. of Plant Pathology
Stellenbosch University, Stellenbosch, Not Applicable, N/A, South Africa	BS	12/2007	Agrisciences

Appointments and Positions

2016 - present Associate Professor, University of Florida, North Florida Research & Education Center, Quincy, FL, United States

2022 - present Project Director, Southeast Partnership for Advanced Renewables from Carinata (SPARC), Quincy, Florida, United States

2017 - 2022 Deputy Project Director, Southeast Partnership for Advanced Renewables from Carinata (SPARC), Quincy, Florida, United States

2012 - 2016 Ph.D. Student, Cornell University, Dept. of Plant Pathology & Plant-Microbe Biology, Ithaca, New York, US

Products

Products Most Closely Related to the Proposed Project

1. Barocco R, Clohessy J, O'Brien G, Dufault N, Anco D, Small I. Sensor-Based Quantification of Peanut Disease Defoliation Using an Unmanned Aircraft System and Multispectral Imagery. Plant Disease. 2024 February 01; 108(2):416-425. Available from: https://apsjournals.apsnet.org/doi/10.1094/PDIS-05-23-0847-RE DOI: 10.1094/PDIS-05-23-0847-RE
2. Sanjel S, Colee J, Barocco R, Dufault N, Tillman B, Punja Z, Seepaul R, Small I. Environmental Factors Influencing Stem Rot Development in Peanut: Predictors and Action Thresholds for Disease Management. Phytopathology®. 2024 February 01; 114(2):393-404. Available from: https://apsjournals.apsnet.org/doi/10.1094/PHYTO-05-23-0164-R DOI: 10.1094/PHYTO-05-23-0164-R
3. Sanjel S, Guerra V, Seepaul R, Mackowiak C, Punja Z, Dufault N, Tillman B, Bradford K, Small I. Application of Hydrothermal Time Models to Predict Sclerotial Germination of *Athelia rolfsii*. Phytopathology®. 2024 January 01; 114(1):126-136. Available from:

https://apsjournals.apsnet.org/doi/10.1094/PHYTO-04-23-0132-R DOI: 10.1094/PHYTO-04-23-0132-R

4. Clohessy J, Sanjel S, O'Brien G, Barocco R, Kumar S, Adkins S, Tillman B, Wright D, Small I. Development of a high-throughput plant disease symptom severity assessment tool using machine learning image analysis and integrated geolocation. Computers and Electronics in Agriculture. 2021 May; 184:106089-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0168169921001071 DOI: 10.1016/j.compag.2021.106089
5. Barocco R, Sanjel S, Dufault N, Barrett C, Broughton B, Wright D, Small I. Peanut Disease Epidemiology Under Dynamic Microclimate Conditions and Management Practices in North Florida. Plant Disease. 2021 September 01; 105(9):2333-2342. Available from: https://apsjournals.apsnet.org/doi/10.1094/PDIS-11-20-2390-RE DOI: 10.1094/PDIS-11-20-2390-RE

Other Significant Products, Whether or Not Related to the Proposed Project

1. Boote K, Seepaul R, Mulvaney M, Hagan A, Bashyal M, George S, Small I, Wright D. Adapting the CROPGRO model to simulate growth and production of *Brassica carinata* , a bio-fuel crop. GCB Bioenergy. 2021 May 14; 13(7):1134-1148. Available from: https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12838 DOI: 10.1111/gcbb.12838
2. Gama A, Perondi D, Dewdney M, Fraisse C, Small I, Peres N. Evaluation of a multi-model approach to estimate leaf wetness duration: an essential input for disease alert systems. Theoretical and Applied Climatology. 2022 April 03; 149(1-2):83-99. Available from: https://link.springer.com/10.1007/s00704-022-04036-1 DOI: 10.1007/s00704-022-04036-1
3. Chaulagain B, Small I, Shine J, Raid R, Rott P. Predictive Modeling of Brown Rust of Sugarcane Based on Temperature and Relative Humidity in Florida. Phytopathology®. 2021 August; 111(8):1401-1409. Available from: https://apsjournals.apsnet.org/doi/10.1094/PHYTO-02-20-0060-R DOI: 10.1094/PHYTO-02-20-0060-R
4. Seepaul R, Kumar S, Boote K, Small I, George S, Wright D. Physiological analysis of growth and development of winter carinata (*Brassica carinata* A. Braun). GCB Bioenergy. 2021 May 05; 13(7):1112-1133. Available from: https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12831 DOI: 10.1111/gcbb.12831
5. Seepaul R, Kumar S, Iboyi J, Bashyal M, Stansly T, Bennett R, Boote K, Mulvaney M, Small I, George S, Wright D. *Brassica carinata* : Biology and agronomy as a biofuel crop. GCB Bioenergy. 2021 February 17; 13(4):582-599. Available from: https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12804 DOI: 10.1111/gcbb.12804

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Certified by Small, Ian in SciENcv on 2024-08-20 13:10:31

Name: Small, Ian M.
ORCID iD: 0000-0001-5406-3486
Position Title: Associate Professor
Primary Organization and Location: University of Florida, Quincy, FL

Synergistic Activities:

1. Project Director for a USDA NIFA workforce development project focused on equipping youth for careers related to agricultural technology
2. Project Director for a USDA NIFA Coordinated Agricultural Project – Southeast Partnership for Advanced Renewables from Carinata (SPARC)
3. Associate Editor for the journal Phytopathology
4. Steering Committee member for the Cotton Research Action Committee of the National Predictive Modeling Tool Initiative https://agpmt.org/ (2020-present),
5. Vice-President of the Florida Phytopathological Society

IDENTIFYING INFORMATION:

NAME: Stofer, Kathryn

ORCID iD: https://orcid.org/0000-0002-3659-490X

POSITION TITLE: Research Associate Professor, STEM Education and Outreach

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Agricultural Education and Communication, Gainesville, FL, US

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Oregon State University, Corvallis, Oregon, US	PHD	06/2013	Science and Mathematics Education, Free-Choice Learning
Boston University, Boston, Massachusetts, US	M.S. Science Journalism	01/2002	Science Journalism
California Institute of Technology, Pasadena, CA, US	B.S. Biology	06/1998	Biology

Appointments and Positions

2021 - present Research Associate Professor, STEM Education and Outreach, University of Florida, Agricultural Education and Communication, Gainesville, FL, US

2013 - 2021 Research Assistant Professor, STEM Education and Outreach, University of Florida, Agricultural Education and Communication, Gainesville, FL, US

2004 - 2009 TerraLink Earth Science News Exhibit Manager, Maryland Science Center, Baltimore, MD, United States

2000 - 2002 Associate Producer, Honeywell/NASA Goddard Space Flight Center, Greenbelt, MD, United States

1998 - 2000 Research Assistant, Research Imaging Center, University of Texas Health Science Center, San Antonio, TX, United States

Products

Products Most Closely Related to the Proposed Project

1. Stofer K. When a Picture Isn't Worth 1000 Words: Learners Struggle to Find Meaning in Data Visualizations. Journal of Geoscience Education. 2018 June 13; 64(3):231-241. Available from: https://www.tandfonline.com/doi/full/10.5408/14-053.1 DOI: 10.5408/14-053.1
2. Stofer K, Rujimora J, et al. Casual conversations in everyday spaces can promote high public engagement with science. International Journal of Science Education, Part B. 2019 November 04; 9(4):296-311. Available from: https://www.tandfonline.com/doi/full/10.1080/21548455.2019.1670882 DOI: 10.1080/21548455.2019.1670882
3. Stofer K, Lundgren L, Dunckel B, James V, Lange M, Krieger J. Public Engagement on Climate and Health in Museums and Participatory Dialogues may Foster Behavior Change. The Journal of STEM Outreach. 2019 June 17; 2(1):-. Available from:

https://www.jstemoutreach.org/article/9137-public-engagement-on-climate-and-health-in-museums-and-participatory-dialogues-may-foster-behavior-change DOI: 10.15695/jstem/v2i1.10

4. Stofer Kathryn A.. Getting Engaged: "Public" Engagement Practices for Researchers. 2017. Available from: http://edis.ifas.ufl.edu/WC272 source-work-id: 0924181420907-26
5. Stofer K, Hanson D, Hecht K. Scientists need professional development to practice meaningful public engagement. Journal of Responsible Innovation. 2022 November 20; 10(1):-. Available from: https://www.tandfonline.com/doi/full/10.1080/23299460.2022.2127672 DOI: 10.1080/23299460.2022.2127672

Other Significant Products, Whether or Not Related to the Proposed Project

1. Clyde, M., Eberhardt, A., Prysby, M., and Stofer, K. Untapped: Accessing Extension to Strengthen Connections Between Citizen Science and Community Decision Making. Journal of Extension. 2018. Available from: https://publons.com/publon/18189650/ WOS:000444432600007. Untapped: Accessing Extension to Strengthen Connections Between Citizen Science and Community Decision Making. Journal of Extension. 2018. Available from: https://publons.com/publon/18189650/ wosuid: WOS:000444432600007
2. Hecht K, Stofer K, Monroe M, Klarenberg G, Nickerson M. Herpetologists' Conservation Research Focus Drives Their Intentions to Participate in Future Public Engagement. [Preprint]. 2021 May 17. DOI: 10.1101/2021.05.14.444251
3. Stofer K. Getting Engaged: Program and Event Planning for Clients with Diverse Abilities. EDIS. 2018 March 26; 2018(2):-. Available from: https://journals.flvc.org/edis/article/view/105180 DOI: 10.32473/edis-wc299-2018
4. Stofer K, Fulton J, Nesbitt H, Prizzia A, Garrett K, Rosario J. Initial social network analysis of producers working towards sustainability suggests weak ties and potential fragmentation. Advancements in Agricultural Development. 2022 January 07; 3(1):4-18. Available from: https://agdevresearch.org/index.php/aad/article/view/141 DOI: 10.37433/aad.v3i1.141
5. Thiel R, Bowling A, Rumble J, McFadden B, Stofer K, Folta K. Impact of teaching methods on learner preferences and knowledge gained when informing adults about gene editing. Advancements in Agricultural Development. 2022 February 02; 3(1):70-86. Available from: https://agdevresearch.org/index.php/aad/article/view/133 DOI: 10.37433/aad.v3i1.133

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Stofer, Kathryn in SciENcv on 2024-06-17 12:11:09

Name: Stofer, Kathryn A.
ORCID iD: https://orcid.org/0000-0002-3659-490X
Position Title: Research Associate Professor
Primary Organization and Location: University of Florida, Gainesville, FL

Synergistic Activities:

1. PreScientist, Inc., Boston, MA. 2017-2023, I served as a STEM professional penpal for a K-12 student (4 students to date) through the program Letters to a PreScientist. I served 2 years on the Advisory Board, and as of January 2020, am on the PreScientist, Inc., Board of Directors, where I am head of the Program and Evaluation Committee; from 2021-2024, I was the Board Clerk/Secretary, and as of 2024, I am the Board Treasurer.
2. From 2015-2020, I facilitated the "talk science with me" public engagement program in Alachua County, Florida. Pairs of scientists had casual conversations with visitors in up to 10 venues, urban and rural, meeting people in everyday spaces. I provided professional learning for more than 60 scientists, undergraduates through professors. I have published an event guide for the program through UF's open access Cooperative Extension journal, *EDIS*. As of 2024, I am updating this program to focus on cancer researchers with the UF Health Cancer Center including creating an online certificate course to prepare researchers for community engagement around cancer research.
3. I have mentored approximately 100 volunteer undergraduate researchers on NSF-funded and other grant-funded research, at least 70 female and 20 under-represented minority students. As of December 2023, I am faculty advisor for the University of Florida chapter of Minorities in Agricultural, Natural Resources, and Related Sciences (MANRRS).
4. I have written 28 practitioner-focused publications through *EDIS*, the University of Florida's online, open-access journal for Cooperative Extension.
5. In 2016, I produced "Community Chats: Climate Change and Health," a total of two public dialogue events and one exhibit mounted at the Florida Museum of Natural History for six months.

IDENTIFYING INFORMATION:

NAME: Sumerlin, Brent S.

ORCID iD: https://orcid.org/0000-0001-5749-5444

POSITION TITLE: George B. Butler Professor of Polymer Chemistry

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Carnegie Mellon University, Pittsburgh, Pennsylvania, United States	Postdoctoral Fellow	05/2003 – 06/2005	Polymer Chemistry
University of Southern Mississippi, Hattiesburg, Mississippi, United States	PHD	05/2003	Polymer Science & Engineering
North Carolina State University, Raleigh, North Carolina, United States	BS	05/1998	Textile Chemistry, Polymer Chem. Conc.

Appointments and Positions

2017 - present George B. Butler Professor of Polymer Chemistry, University of Florida, Gainesville, Florida, United States

2015 - 2017 Professor, Department of Chemistry, University of Florida, Gainesville, Florida, United States

2012 - 2015 Associate Professor, Department of Chemistry, University of Florida, Gainesville, Florida, United States

2009 - 2012 Harold Jeskey Associate Professor of Chemistry, Southern Methodist University, Dallas, Texas, United States

2007 - 2009 Harold Jeskey Assistant Professor of Chemistry, Southern Methodist University, Dallas, Texas, United States

2005 - 2007 Assistant Professor, Southern Methodist University, Dallas, Texas, United States

2003 - 2005 Visiting Assistant Professor, Carnegie Mellon University, Pittsburgh, Pennsylvania, United States

Products

Products Most Closely Related to the Proposed Project

1. Lessard JJ, Scheutz GM, Sung SH, Lantz KA, Epps TH 3rd, Sumerlin BS. Block Copolymer Vitrimers. J Am Chem Soc. 2020 Jan 8;142(1):283–289. PubMed PMID: 31794219.
2. Sims M, Lessard J, Bai L, Sumerlin B. Functional Diversification of Polymethacrylates by Dynamic β-Ketoester Modification. Macromolecules. 2018 August 14; 51(16):6380-6386. Available from: https://pubs.acs.org/doi/10.1021/acs.macromol.8b01343 DOI: 10.1021/acs.macromol.8b01343
3. Lessard J, Garcia L, Easterling C, Sims M, Bentz K, Arencibia S, Savin D, Sumerlin B. Catalyst-Free Vitrimers from Vinyl Polymers. Macromolecules. 2019 February 20; 52(5):2105-

2111. Available from: https://pubs.acs.org/doi/10.1021/acs.macromol.8b02477 DOI: 10.1021/acs.macromol.8b02477

4. Scheutz G, Lessard J, Sims M, Sumerlin B. Adaptable Crosslinks in Polymeric Materials: Resolving the Intersection of Thermoplastics and Thermosets. Journal of the American Chemical Society. 2019 September 16; 141(41):16181-16196. Available from: https://pubs.acs.org/doi/10.1021/jacs.9b07922 DOI: 10.1021/jacs.9b07922
5. Sumerlin BS. Next-generation self-healing materials. Science. 2018 October 12; 362(6411):150-151. Available from: http://dx.doi.org/10.1126/science.aau6453

Other Significant Products, Whether or Not Related to the Proposed Project

1. Carmean R, Becker T, Sims M, Sumerlin B. Ultra–High Molecular Weights via Aqueous Reversible–Deactivation Radical Polymerization. Chem. 2017 January; 2(1):93–101. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2451929416302728 DOI: 10.1016/j.chempr.2016.12.007
2. Mondal S, Lessard J, Meena C, Sanjayan G, Sumerlin B. Janus Cross-links in Supramolecular Networks. Journal of the American Chemical Society. 2022 January 05; 144(2):845-853. Available from: https://pubs.acs.org/doi/10.1021/jacs.1c10606 DOI: 10.1021/jacs.1c10606
3. Sun H, Kabb C, Dai Y, Hill M, Ghiviriga I, Bapat A, Sumerlin B. Macromolecular metamorphosis via stimulus-induced transformations of polymer architecture. Nature Chemistry. 2017; 9(8):817-823. Available from: https://www.nature.com/articles/nchem.2730 DOI: 10.1038/nchem.2730
4. Cobo I, Li M, Sumerlin B, Perrier S. Smart hybrid materials by conjugation of responsive polymers to biomacromolecules. Nature Materials. 2014 November 17; 14(2):143–159. Available from: https://www.nature.com/articles/nmat4106 DOI: 10.1038/nmat4106
5. Miao Z, Gonsales S, Ehm C, Mentink-Vigier F, Bowers C, Sumerlin B, Veige A. Cyclic polyacetylene. Nature Chemistry. 2021 June 03; 13(8):792-799. Available from: https://www.nature.com/articles/s41557-021-00713-2 DOI: 10.1038/s41557-021-00713-2

Certification:

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Certified by Sumerlin, Brent S. in SciENcv on 2024-06-10 10:24:42

Synergistic Activities

Brent S. Sumerlin, Department of Chemistry, University of Florida

1. Associate Editor, *ACS Macro Letters* (American Chemical Society, 2015-)

2. Member of the Committee on Polymers (Panel 7) of the Petroleum Research Fund of the American Chemical Society (2019-)

3. Organizer for the annual Symposium on Stimuli-Responsive Materials held in Windsor, CA (2012-)

4. Member, External Advisory Board of the NSF Center for Sustainable Polymers at the University of Minnesota (2020-2022)

5. Member, Scientific Advisory Board for the Department of Textile Engineering, Chemistry, and Science at North Carolina State University (2013-)

IDENTIFYING INFORMATION:

NAME: Turner, Kevin

ORCID iD: https://orcid.org/0000-0003-4963-4568

POSITION TITLE: Professor

PRIMARY ORGANIZATION AND LOCATION: Department of Mechanical Engineering & Applied Mechanics; Secondary Appointment in Materials Science and Engineer, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	Postdoctoral Fellow	06/2004 - 07/2005	Materials Science and Engineering
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	PHD	05/2004	Mechanical Engineering
Massachusetts Institute of Technology, Cambridge, Massachusetts, United States	MS	05/2001	Mechanical Engineering
Johns Hopkins University, Baltimore, Maryland, United States	BS	05/1999	Mechanical Engineering

Appointments and Positions

2016 - present	Professor, Department of Mechanical Engineering & Applied Mechanics; Secondary Appointment in Materials Science and Engineer, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2019 - present	Department Chair, Department of Mechanical Engineering & Applied Mechanics, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2016 - 2019	Graduate Group Chair, Department of Mechanical Engineering & Applied Mechanics, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2012 - 2017	Gabel Family Associate Professor, Departments of Mechanical Engineering & Applied Mechanics (primary) and Materials Science and Engineering (secondary), University of Pennsylvania, Philadelphia, Pennsylvania, United States
2012 - 2017	Director, Quattrone Nanofabrication Facility, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2011 - 2023	Co-founder, Technical advisor, systeMECH, Inc. (formerly systeMECH, LLC), Madison, Wisconsin, United States
2011 - 2011	Associate Professor, Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin, United States
2005 - 2011	Assistant Professor, Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin, United States
2004 - 2005	Postdoctoral Associate and Lecturer, Department of Materials Science, Massachusetts Institute of Technology, Cambridge, Massachusetts, United States

Products

Products Most Closely Related to the Proposed Project

1. Iyer GM, Zaccarin A, Olsson RH, Turner KT. Fabrication and Characterization of Cellulose-Based Materials for Biodegradable Soil Moisture Sensors. 2022 IEEE Sensors. 2022 IEEE Sensors; 2022; Dallas, TX, USA. IEEE; c2022. DOI: 10.1109/SENSORS52175.2022.9967089
2. Zaccarin A, Iyer GM, Olsson R, Turner KT. Fabrication and Characterization of Soil Moisture Sensors on a Biodegradable, Cellulose-Based Substrate. IEEE Sensors Journal. 2024 March 15; 24(6):7235. DOI: 10.1109/JSEN.2023.3299430
3. Mariani L, Johnson W, Considine J, Turner K. Printing and mechanical characterization of cellulose nanofibril materials. CELLULOSE. MAR; 26(4):2639-2651. DOI: 10.1007/s10570-019-02247-w
4. Kagan C, Arnold D, Cappelleri D, Keske C, Turner K. Special report: The Internet of Things for Precision Agriculture (IoT4Ag). Computers and Electronics in Agriculture. 2022 May 01; 196:106742. Available from: https://www.sciencedirect.com/science/article/pii/S016816992200059X DOI: 10.1016/j.compag.2022.106742
5. Carlson A, Kim-Lee H, Wu J, Elvikis P, Cheng H, Kovalsky A, Elgan S, Yu Q, Ferreira P, Huang Y, Turner K, Rogers J. Shear-enhanced adhesiveless transfer printing for use in deterministic materials assembly. APPLIED PHYSICS LETTERS. JUN; 98(26). DOI: 10.1063/1.3605558

Other Significant Products, Whether or Not Related to the Proposed Project

1. Levine DJ, Turner KT, Pikul JH. Materials with Electroprogrammable Stiffness. Adv Mater. 2021 Sep;33(35):e2007952. PubMed PMID: 34245062.
2. Pande S, Turner K. Geometric optimization of pillars for enhanced adhesion. Extreme Mechanics Letters. 2023 March; 59:101969-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2352431623000159 DOI: 10.1016/j.eml.2023.101969
3. Levine DJ, Iyer GM, Daelan Roosa R, Turner KT, Pikul JH. A mechanics-based approach to realize high-force capacity electroadhesives for robots. Sci Robot. 2022 Nov 30;7(72):eabo2179. PubMed PMID: 36449630.
4. Luo A, Zhang H, Turner K. Machine learning-based optimization of the design of composite pillars for dry adhesives. Extreme Mechanics Letters. 2022 July; 54:101695-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2352431622000505 DOI: 10.1016/j.eml.2022.101695
5. Luo A, Turner K. Mechanics of crack path selection in microtransfer printing: Challenges and opportunities for process control. 2020; 143:104066. DOI: 10.1016/j.jmps.2020.104066

Certification:

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Certified by Turner, Kevin in SciENcv on 2024-08-07 17:33:52

Name: Kevin Turner
ORCID iD:
Position Title: Professor
Primary Organization and Location: University of Pennsylvania

Synergistic Activities:

1. Outreach to K-12 students and the public on concepts in materials and manufacturing. Recent example: Turner and students from his group presented a demo on 'sticky' materials to a diverse audience at Philly Materials Science and Engineering Day (Feb. 2024). Engaged approximately 75 kids, between the ages of 5 and 14.
2. Mechanics education to practicing engineers and researchers: Invited Short course instructor at the Adhesion Society Annual meeting (2014-2023). Turner has presented annually on aspects of micro-/nano-scale engineering in adhesion science to researchers from academia and industry. The size of the class has ranged from 20 to over 60 students; participants from industry typically make up more than half of the audience. This event allows Turner to communicate leading-edge concepts in adhesion mechanics to engineers in industry.
3. Course on materials and manufacturing: Developed and taught a graduate course on the materials and manufacturing in design (most recently in Fall 2023). Course covers advanced topics in materials and manufacturing in an integrated manner. Digital manufacturing and opportunities for materials design are discussed.

IDENTIFYING INFORMATION:

NAME: Weiner, Steven S

ORCID iD: https://orcid.org/0009-0004-3070-9034

POSITION TITLE: Sr. Director for Innovation and Technology and Lecturer

PRIMARY ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
Harvard Law School, Cambridge, Massachusetts, United States	JD	05/1990	Law
MIT, Cambridge, Massachusetts, United States	MS	06/1987	Electrical Engineering & Computer Science
University of Pennsylvania, Philadelphia, Pennsylvania, United States	Bachelor of Science and Engineering	05/1985	Systems Science and Engineering

Appointments and Positions

2020 - present	Sr. Director for Innovation and Technology and Lecturer, University of Pennsylvania, Philadelphia, Pennsylvania, United States
2017 - present	Lecturer, part-time, The Wharton School, Philadelphia, Pennsylvania, United States
2019 - 2020	Renowned Fellow, Intellectual Property, SRI International, Menlo Park, California, United States
2011 - 2018	Deputy General Counsel and Chief Patent Officer, SRI International, Menlo Park, California, United States
2002 - 2010	Partner, Davis Polk & Wardwell, Menlo Park, California, United States
1998 - 2002	Vice President, Intellectual Property & Strategic Planning, SRI International, Menlo Park, California, United States
1995 - 1998	Senior Counsel, IP and Media, SGI, Mountain View, California, United States
1990 - 1995	Associate, Intellectual Property, Irell & Manella, Los Angeles, California, United States

Products

Products Most Closely Related to the Proposed Project

1. US10679063 Recognizing Salient Video Events Through Learning-based Multimodal Analysis of Visual Features and Audio-based Analytics. US. 2020 June.
2. US9501745 Method, System and Device for Inferring a Mobile User's Current Context and Proactively Providing Assistance. US. 2016 November.
3. US10163058 Method, system and device for inferring a mobile user's current context and proactively providing assistance. US. 2018 December.
4. US9466013 Computer Vision as a Service. US. 2016 October.

5. US9152870 Computer Vision as a Service. US. 2015 October.

Other Significant Products, Whether or Not Related to the Proposed Project

1. 1 ed. In: Berg T, Cholij R, Ravenscroft S, editors. Patents on Life [Internet] Cambridge University Press; 2019-09-28. -p. Available from: https://www.cambridge.org/core/product/identifier/9781108659802/type/book DOI: 10.1017/9781108659802
2. US9015099 Method, System and Device for Inferring a Mobile User's Current Context and Proactively Providing Assistance. US. 2015 April.
3. US8928582 Method for Adaptive Interaction with a Legacy Software Application. 2015 January.

Certification:

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Certified by Weiner, Steven S in SciENcv on 2024-07-16 15:32:20

Name: Steven S. Weiner
ORCID iD: https://orcid.org/0009-0004-3070-9034
Position Title: Sr. Director for Innovation and Technology and Lecturer
Primary Organization and Location: University of Pennsylvania, Philadelphia PA, USA

Synergistic Activities:

1. **Innovative teaching and training**: I developed from scratch an innovative course for aspiring entrepreneurs entitled *IP Strategy for the Innovation Driven Enterprise*. I have taught this course to Wharton MBA students and undergraduates every year since 2017, and as of August 2024 will teach it to Penn Engineering students as well. The course is very popular and is consistently highly rated by students. My course includes interactive exercises and role-playing team projects based on real-world technologies, as well as traditional lectures and assignments. I created all of the content for this innovative course.
2. I served as a senior leader of commercialization and IP strategy at SRI International for 14 years. Highlights include developing the patent portfolio for inventions later licensed to SRI start-up **Siri**; these patents were also asserted against Microsoft, resulting in > $200M jury verdict.
3. I was co-founder and inaugural leader of the Transactional Intellectual Property team for renowned law firm Davis Polk from 2002-2010, in the firm's Silicon Valley office. I advised clients on a wide range of sophisticated IP matters, including leading high-tech and media companies, disruptive start-ups, and investors.

IDENTIFYING INFORMATION:

NAME: Yeo, M. Lisa

ORCID iD: https://orcid.org/0000-0002-6648-3557

POSITION TITLE: Assistant Professor

PRIMARY ORGANIZATION AND LOCATION: University of California Merced, Management, School of Engineering, Merced, CA, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Alberta, Edmonton, AB, CA	PhD	08/2012	Accounting, Operations & Information Systems
University of Alberta, Edmonton, AB, CA	MBA	05/2006	International Business
University of Waterloo, Waterloo, ON, CA	B. Math, Honours	05/1996	Applied Math

Appointments and Positions

2016 - present Assistant Professor, University of California Merced, Management, School of Engineering, Merced, CA, United States

2019 - 2019 Visiting Assistant Professor, University of Calgary, Haskayne School of Business, Calgary, Alberta, Canada

2012 - 2017 Assistant Professor, Loyola University Maryland, Information Systems & Operations Management, Baltimore, MD, US

Products

Products Most Closely Related to the Proposed Project

1. Yeo M, Keske C. Understanding technology acceptance disparity in digital agriculture. ASA 2024 Annual Conference. 2024 August.
2. Yeo M, Rolland E, Ulmer J, Patterson R. How Customer Demand Reactions Impact Technology Innovation and Security. ACM Transactions on Management Information Systems. 2022 April 11; 13(3):1-17. Available from: https://dl.acm.org/doi/10.1145/3505227 DOI: 10.1145/3505227
3. Bhappu AD, Blomqvist K, Andreeva T, Zappa P, Yeo ML, Lempiälä T. Providers' Initial Trust on an Organization-Sponsored Sharing Platform: The Framing of Coworker Collaborative Consumption. Front Psychol. 2020;11:2174. PubMed Central PMCID: PMC7505737.
4. Yeo M, Rolland E, Ulmer J, Patterson R. Risk Mitigation Decisions for IT Security. ACM Transactions on Management Information Systems. 2014 April; 5(1):1-21. Available from: https://dl.acm.org/doi/10.1145/2576757 DOI: 10.1145/2576757
5. Bhappu A, Lempiälä T, Yeo M. Platform Service Designs: A Comparative Case Analysis of Technology Features, Affordances, and Constraints for Ridesharing. Digital. 2022 June 05; 2(2):320-332. Available from: https://www.mdpi.com/2673-6470/2/2/18 DOI:

10.3390/digital2020018

Other Significant Products, Whether or Not Related to the Proposed Project

1. Croson R, Schultz K, Siemsen E, Yeo M. Behavioral operations: The state of the field. Journal of Operations Management. 2012 December 12; 31(1-2):1-5. Available from: https://onlinelibrary.wiley.com/doi/10.1016/j.jom.2012.12.001 DOI: 10.1016/j.jom.2012.12.001
2. Kolfal B, Patterson R, Yeo M. Market Impact on IT Security Spending. Decision Sciences. 2013 June 19; 44(3):517-556. Available from: https://onlinelibrary.wiley.com/doi/10.1111/deci.12023 DOI: 10.1111/deci.12023
3. Arazy O, Nov O, Patterson R, Yeo L. Information Quality in Wikipedia: The Effects of Group Composition and Task Conflict. Journal of Management Information Systems. 2014 December 08; 27(4):71-98. Available from: https://www.tandfonline.com/doi/full/10.2753/MIS0742-1222270403 DOI: 10.2753/MIS0742-1222270403
4. Arazy O, Yeo L, Nov O. Stay on the Wikipedia task: When task-related disagreements slip into personal and procedural conflicts. Journal of the American Society for Information Science and Technology. 2013 August; 64(8):1634-1648. Available from: https://onlinelibrary.wiley.com/doi/10.1002/asi.22869 DOI: 10.1002/asi.22869
5. Yeo M, Arazy O. What Makes Corporate Wikis Work? Wiki Affordances and Their Suitability for Corporate Knowledge Work. In: Hutchison D, Kanade T, Kittler J, Kleinberg J, Mattern F, Mitchell J, Naor M, Nierstrasz O, Pandu Rangan C, Steffen B, Sudan M, Terzopoulos D, Tygar D, Vardi M, Weikum G, editors. Lecture Notes in Computer Science [Internet] Berlin, Heidelberg: Springer Berlin Heidelberg; 2012. Chapter Chapter 14174-190p. Available from: http://link.springer.com/10.1007/978-3-642-29863-9_14 DOI: 10.1007/978-3-642-29863-9_14

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Certified by Yeo, M. Lisa in SciENcv on 2024-06-28 11:17:57

NSF Synergistic Activities

Yeo, M. Lisa
https://orcid.org/0000-0002-6648-3557
Assistant Professor, University of California Merced, Merced, CA, US

1. IoT4Ag NSF ERC Diversity and Culture of Inclusion (DCI) Co-lead (2023-); develop/guide Center-wide efforts in consultation with DCI Advisory Board; coordinate the Center's EWD/DCI activities at UC Merced.
2. UC Merced School of Engineering AgTech Major: Member of committee developing new AgTech major.
3. Panelist *Expert Briefing: Cultivating Data Security Practices in Precision Agriculture – California Council on Science & Technology*. We broadly explored the benefits of precision agriculture and the susceptibility of its data to theft or corruption, and the potential impacts of losing these data. (October 6, 2022. https://ccst.us/register-cultivating-data-security-practices-in-precision-agriculture/)
4. Scientific Review Panel Member for USDA NIFA 2024, NSF SaTC 2023; reviewed assigned grant proposals; participated in full panel review; led discussion and wrote final review summaries for assigned proposals
5. Faculty Advisory Board Member, CITRIS Policy Lab (2020-), supporting interdisciplinary technology policy research and engagement to better ensure development and deployment of technology in the interest of society.

IDENTIFYING INFORMATION:

NAME: Zare, Alina

ORCID iD: https://orcid.org/0000-0002-4847-7604

POSITION TITLE: Associate Dean for Research and Facilities

PRIMARY ORGANIZATION AND LOCATION: University of Florida, Herbert Wertheim College of Engineering, Gainesville, Florida, United States

Professional Preparation:

ORGANIZATION AND LOCATION	DEGREE (if applicable)	RECEIPT DATE	FIELD OF STUDY
University of Florida, Gainesville, FL, USA	MS	08/2008	Computer Engineering
University of Florida, Gainesville, FL, US	BENG	05/2003	Computer Engineering
University of Florida, Gainesville, Fl, United States	Ph.D.	12/2010	Computer & Information Science & Engineering

Appointments and Positions

2022 - present Associate Dean for Research and Facilities, University of Florida, Herbert Wertheim College of Engineering, Gainesville, Florida, United States

2020 - present Professor, University of Florida, Electrical and Computer Engineering, Gainesville, FL, United States

2016 - 2020 Associate Professor, University of Florida, Electrical and Computer Engineering, Gainesville, FL, US

2016 - 2016 Associate Professor, University of Missouri, Electrical and Computer Engineering, Columbia, Missouri, US

2010 - 2016 Assistant Professor, University of Missouri, Electrical and Computer Engineering, Columbia, Missouri, US

Products

Products Most Closely Related to the Proposed Project

1. Yu G, Zare A, Xu W, Matamala R, Reyes-Cabrera J, Fritschi F, Juenger T. Weakly Supervised Minirhizotron Image Segmentation with MIL-CAM. Lecture Notes in Computer Science [Internet] Cham: Springer International Publishing; 2020. Chapter Chapter 30433-449p. Available from: https://link.springer.com/10.1007/978-3-030-65414-6_30 DOI: 10.1007/978-3-030-65414-6_30
2. Peeples J, Xu W, Zare A. Histogram Layers for Texture Analysis. IEEE Transactions on Artificial Intelligence. 2022; 3(4):541-552. Available from: https://ieeexplore.ieee.org/document/9652037/ DOI: 10.1109/TAI.2021.3135804
3. Meerdink S, Bocinsky J, Zare A, Kroeger N, McCurley C, Shats D, Gader P. Multitarget Multiple-Instance Learning for Hyperspectral Target Detection. IEEE Transactions on Geoscience and Remote Sensing. 2022; 60:1-14. Available from:

https://ieeexplore.ieee.org/document/9375470/ DOI: 10.1109/TGRS.2021.3060966

4. Meerdink S, Hiatt D, Flory S, Zare A. Dealing with imperfect data for invasive species detection using multispectral imagery. Ecological Informatics. 2024 March; 79:102432-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1574954123004612 DOI: 10.1016/j.ecoinf.2023.102432
5. Castillo–Argaez R, Sapes G, Mallen N, Lippert A, John G, Zare A, Hammond W. Spectral ecophysiology: hyperspectral pressure–volume curves to estimate leaf turgor loss. New Phytologist. 2024 March 14; 242(3):935-946. Available from: https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.19669 DOI: 10.1111/nph.19669

Other Significant Products, Whether or Not Related to the Proposed Project

1. McCurley C, Zare A. Segmentation Pseudolabel Generation Using the Multiple Instance Learning Choquet Integral. IEEE Transactions on Fuzzy Systems. 2024; 32(4):1927–1937. Available from: https://ieeexplore.ieee.org/document/10336530/ DOI: 10.1109/TFUZZ.2023.3338049
2. Graves S, Marconi S, Stewart D, Harmon I, Weinstein B, Kanazawa Y, Scholl V, Joseph M, McGlinchy J, Browne L, Sullivan M, Estrada-Villegas S, Wang D, Singh A, Bohlman S, Zare A, White E. Data science competition for cross-site individual tree species identification from airborne remote sensing data. PeerJ. 2023 December 21; 11:e16578-. Available from: https://peerj.com/articles/16578 DOI: 10.7717/peerj.16578
3. Guo X, Tseung C, Zare A, Liu T. Hyperspectral image analysis for the evaluation of chilling injury in avocado fruit during cold storage. Postharvest Biology and Technology. 2023 December; 206:112548–. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0925521423003095 DOI: 10.1016/j.postharvbio.2023.112548
4. Du X, Zare A. Multiresolution Multimodal Sensor Fusion for Remote Sensing Data With Label Uncertainty. IEEE Transactions on Geoscience and Remote Sensing. 2020; 58(4):2755–2769. Available from: https://ieeexplore.ieee.org/document/8931670/ DOI: 10.1109/TGRS.2019.2955320
5. Smith H, Dubeux J, Zare A, Wilson C. Assessing Transferability of Remote Sensing Pasture Estimates Using Multiple Machine Learning Algorithms and Evaluation Structures. Remote Sensing. 2023 June 05; 15(11):2940–. Available from: https://www.mdpi.com/2072-4292/15/11/2940 DOI: 10.3390/rs15112940

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Zare, Alina in SciENcv on 2024-06-21 17:19:16

Name: Zare, Alina
ORCID iD: 0000-0002-4847-7604
Position Title: Associate Dean of Research and Facilities
Primary Organization and Location: University of Florida, Gainesville, FL

Synergistic Activities:

1. Served as an initiative lead for the IEEE Geoscience and Remote Sensing Society Education and IDEA (Inspire, Develop, Empower, Advance) Committee
2. Served as an Executive Board Member for the North American Plant Phenotyping Network (NAPPN)
3. Revised undergraduate and graduate level Supervised Machine Learning and Unsupervised Machine Learning courses to be student-centered active learning courses which include in-class individual and group activities.
4. Participated in technology transfer to multiple government defense agencies by providing programs, papers, and presentations.
5. Served as the formal mentor to two current and two former junior faculty members across Engineering and Agronomy and served as a mentor in the UF Women Lead program, a campus-wide leadership development program for early career women scholar.

APPENDIX XII. CURRENT AND PENDING SUPPORT

The current and pending support documentation for the ERC Leadership team, and for any faculty receiving $80,000 or more from the ERC begins on the next page.

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Allen, Mark

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Compact Wide-band Frequency Agile Microwave Filters for WARCHAMP Phase 1

***Status of Support:** Current

Proposal/Award Number: WARCHAMP PHASE I

***Source of Support:** NEXTFLEX (DEPARTMENT OF THE AIR FORCE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $759,388

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1

***Overall Objectives:** We envision creating a 4x4 planar panel of tunable magnetic bias circuits and high selectivity Yttrium Iron Garnet (YIG) filters on a Ku-band lattice spacing. This will enable every element in a digital phased array to have a high performance tunable bandpass, bandstop, or bandpass/bandstop combination filter that is tunable from 2-18 GHz.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** All-Optical Control of Isolated High Voltage Power Systems Using Integrated Electronic, Photonic, and Microfabricated Sensing and Breaker Technology

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** ADVANCED RESEARCH PROJECTS AGENCY-ENERGY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2023

***Proposal/Active Project End Date: (MM/YYYY):** 11/2026

***Total Anticipated Proposal/Project Amount:** $2,620,244

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1
2026	0.1

***Overall Objectives:** This project aims to develop a heterogeneous chiplet platform that integrates high-speed gate driving, optical power delivery and signal isolation, and non-invasive remote sensing and protection for utilizing next-generation wide bandgap (WBG) and ultra-wide bandgap (UWBG) power devices.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Architecture and Magnetics for Vertical Power Delivery in Chiplet Systems

***Status of Support:** Current

Proposal/Award Number: SUB0000758

***Source of Support:** PRINCETON UNIVERSITY (TAIWAN SEMICONDUCTOR MANUFACTURING CO.

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $75,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** The University of Pennsylvania, in collaboration with Princeton University, proposes a program in the use of microfabrication-based sequential multilayer deposition (SMD) to create magnetically enhanced via analogs for power delivery in compact systems, and deliver them to Princeton for testing.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Development and Clinical Validation of Noninvasive Diagnostics for Mitochondrial Disease

***Status of Support:** Current

Proposal/Award Number: GRT-00002453-XX

***Source of Support:** CHILDREN'S HOSPITAL OF PHILADELPHIA (CHOP)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2024

***Total Anticipated Proposal/Project Amount:** $249,552

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** We will fabricate MEMS-based oxygen tissue sensors to be used in the confirmation of the hypothesis that mitochondrial deficiencies manifest in different oxygen uptake profiles in muscle tissue. All animal work will be done at CHOP, none at Penn.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Advanced Magnetics for Power Supplies

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** DEFENSEWERX

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2022

***Proposal/Active Project End Date: (MM/YYYY):** 07/2025

***Total Anticipated Proposal/Project Amount:** $425,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1

***Overall Objectives:** Using nano fabrication techniques to create high performance magnetic cores for compact power supplies.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NNCI: Establishment of a Nanotechnology User Node at the University of Pennsylvania

***Status of Support:** Current

Proposal/Award Number: ECCS-2025608

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,200,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1.5
2025	1.5

***Overall Objectives:** MANTH's vision is to be a resource that serves, engages and inspires researchers, innovators, educators, and the general public in the area of nanotechnology. We strive to be a catalytic force in the education, discovery and translation of nanoscience and technology in the industry-dense and academically-rich environment of Philadelphia and the surrounding mid-Atlantic region. MANTH serves nearly 700 users, with over 40% of these users currently external to Penn.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.12
2025	0.12

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.3
2027	0.29
2028	0.29
2029	0.15
2030	0.1

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas,

***Statement of Potential Overlap:** None - THIS PROPOSAL

***Proposal/Active Project Title:** Restoring movement and sensation to the hand of paralyzed Veterans

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** OHIO STATE UNIVERSITY (DEPARTMENT OF DEFENSE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2029

***Total Anticipated Proposal/Project Amount:** $659,995

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.1

Year	Person Months
2027	0.1
2028	0.1
2029	0.1

***Overall Objectives:** We will utilize MEMS-based force, shear, and pressure sensors to provide signals as inputs to electronics systems with the ultimate goal to re-enervate paralyzed limbs.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Equipment: MRI: Track 1 Acquisition of a Multi-Technique Scanning XPS/AES System for Energy, Biomaterials, and Semiconductor Research, Education, and Outreach

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024

***Proposal/Active Project End Date: (MM/YYYY):** 05/2027

***Total Anticipated Proposal/Project Amount:** $1,232,750

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1
2026	0.1
2027	0.1

***Overall Objectives:** To acquire a multi-technique surface spectroscopy system based on scanning X-ray photoelectron spectroscopy (XPS) and scanning Auger electron spectroscopy (AES) along with other electron spectroscopies, to be installed in a newly constructed user facility for broad access to multiple academic and industry users.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** A home-use, context-aware, bidirectional brain computer interface to enable closedloop sensorimotor reanimation

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** OHIO STATE UNIVERSITY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2024

***Proposal/Active Project End Date: (MM/YYYY):** 03/2029

***Total Anticipated Proposal/Project Amount:** $2,174,796

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1
2026	0.1
2027	0.1
2028	0.1
2029	0.1

***Overall Objectives:** Fabricate and characterize MEMS-based tactile sensors suitable for a wearable interface for sensorimotor reanimation.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Increasing Diversity and Access to Semiconductor and Silicon-Adjacent Industries through Dual Enrollment

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** COMMUNITY COLLEGE OF PHILADELPHIA

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2027

***Total Anticipated Proposal/Project Amount:** $108,100

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1
2026	0.1
2027	0.1

***Overall Objectives:** Assist in workforce development opportunities for pre-college students in the nanotechnology space.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729–3733 and 3802.

Certified by Allen, Mark in SciENcv on 2024-09-03 16:08:43

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Arnold, David P

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0003-2515-7218

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Heterogenous Convolution ASIC for AI Acceleration (HeICat)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** ONR

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2023

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $600,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,25
2025	0.25
2026	0,25

***Overall Objectives:** Design, prototype and test an ASIC processor for accelerating data processing and AI/machine-learning application

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** Miniaturized and Power-Efficient MMW Arrays with Precise Electrical and Thermal Optimization for Future Low Cost Standardization

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** DARPA

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2021

***Proposal/Active Project End Date: (MM/YYYY):** 09/2024

***Total Anticipated Proposal/Project Amount:** $499,171

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.1
2024	0.1

***Overall Objectives:** Develop millimeter wave array transceivers via heterogeneous integration of RFIC's antennas and power amplifiers.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** NSF

***Primary Place of Performance:** U Penn, Purdue, UC Merced, and UF

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $31,014,717

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.8
2022	0.8
2023	0.8
2024	0.8
2025	0.8

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment, To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:**	Phase II IUCRC University of Florida: Center for Multi-functional Integrated System Technology (MIST)
***Status of Support:**	Current
Proposal/Award Number:	IIP-1939009
***Source of Support:**	NSF
***Primary Place of Performance:**	University of Florida
***Proposal/Active Project Start Date: (MM/YYYY):**	04/2020
***Proposal/Active Project End Date: (MM/YYYY):**	03/2025
***Total Anticipated Proposal/Project Amount:**	$750,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.5
2022	0.1
2023	0.1
2024	0.1
2025	0.1

***Overall Objectives:** The goal of this grant is to sustain an NSF Industry/University Collaborative Research Center (I/UCRC) involving University of Florida, University of Central Florida, and University of Virginia in the area of multi-functional integrated systems.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	Penn (NSF is prime)
***Primary Place of Performance:**	Gainesville, FL
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2025
***Proposal/Active Project End Date: (MM/YYYY):**	08/2030
***Total Anticipated Proposal/Project Amount:**	$5,691,522

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1.14
2027	1.14
2028	1.09
2029	0.97
2030	0.74

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come

***Statement of Potential Overlap:** N/A, THIS PROPOSAL

***Proposal/Active Project Title:** Enhancing the Throughput of Florida's Semiconductor Workforce Pipeline

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSTC/NatCast

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 12/2026

***Total Anticipated Proposal/Project Amount:** $2,150,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1

***Overall Objectives:** Expand the semiconductor workforce pipeline in the State of Florida.

***Statement of Potential Overlap:** no overlap

***Proposal/Active Project Title:** DURIP: G-Band Test and Measurement Capabilities for Component Characterization, Material Measurement, and System Development

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** ONR

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2024

***Proposal/Active Project End Date: (MM/YYYY):** 11/2025

***Total Anticipated Proposal/Project Amount:** $322,970

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** Acquire G-band test and measurement equipment.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** DURIP: SF-COMS: Secure Free-space & On-Chip Mid-IR System for Defense Communication & Sensing

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** ARO

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2024

***Proposal/Active Project End Date: (MM/YYYY):** 11/2025

***Total Anticipated Proposal/Project Amount:** $100,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** Acquire Mid-IR test and measurement capabilities.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Collaborative Research: The Next Generation of U.S. Geospace Research Facilities

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NJIT (prime is NSF)

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 11/2023

***Proposal/Active Project End Date: (MM/YYYY):** 10/2028

***Total Anticipated Proposal/Project Amount:** $523,893

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	0.5
2026	0.5
2027	0.5
2028	0.5

***Overall Objectives:** Deploy, support, and monitor ELF/VLF radio receivers in antarctic locations.

***Statement of Potential Overlap:** None

In-Kind Contributions

***Status of Support:** Current

***Source of Support:** Institute for Defense Analysis (IDA) [DARPA is the prime]

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 01/2022

***Summary of In-Kind Contribution:** Travel support for serving on DARPA MEC advisory committee

***U.S. Dollar Value of In-Kind Contribution:** $9,000

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2022	0.03
2023	0.03
2024	0.03

***Overall Objectives:** The purpose of the MEC is to prove the Microsystems Technology Office (MTO) with a continuing and independent assessment of the state of advanced microelectronics and microsystems science and technology, as it relates to DoD and national security issues. Estimated support is approximately $3000/yr x 3 years = $9000.

***Statement of Potential Overlap:** No potential overlap

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Arnold, David in SciENcv on 2024-09-05 09:34:58

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person,

*NAME: Arratia, Paulo

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0002-2566-2663

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** NRT: CLIMATE-CARE: Climate Action and Resilience for Extreme Urban Heat

***Status of Support:** Current

Proposal/Award Number: DGE-2346010

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2029

***Total Anticipated Proposal/Project Amount:** $3,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,1
2026	0.1
2027	0,1
2028	0,1
2029	0.1

***Overall Objectives:** The Project will train the next-generation sustainability workforce via nature-inspired solutions to mitigate extreme heat in an urban environment. It will bring scientists, engineers, and designers together through the convergence of material advances, downscaling and upscaling design and additive manufacturing of biobased composites, and data-driven deep learning and sensing of environmental temperatures.

***Statement of Potential Overlap:** no overlap,

***Proposal/Active Project Title:** Probing the role of Selenomonas sputigena in supragingival biofilm spatial structuring and virulence

***Status of Support:** Current

Proposal/Award Number: 1-K99-DE-033428-01

***Source of Support:** NATIONAL INSTITUTE OF DENTAL AND CRANIOFACIAL RESEARCH

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 02/2024

***Proposal/Active Project End Date: (MM/YYYY):** 01/2026

***Total Anticipated Proposal/Project Amount:** $248,724

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5
2026	0.5

***Overall Objectives:** This proposal is related to biofilm formation in oral cavities, in particular at the junction between gum and teeth bone.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Monell Mouthfeel Consortium

***Status of Support:** Current

Proposal/Award Number: MCSC

***Source of Support:** MONELL CHEMICAL SENSES CENTER

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $197,690

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1

***Overall Objectives:** Investigate the elasto-tribological properties of fat emulsions.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Elasto-electro-chemical materials for dexterous self-sufficient soft machines (PI - James Pikul)

***Status of Support:** Current

Proposal/Award Number: N00014-22-1-2569

***Source of Support:** OFFICE OF NAVAL RESEARCH

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2022

***Proposal/Active Project End Date: (MM/YYYY):** 08/2026

***Total Anticipated Proposal/Project Amount:** $1,100,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1
2026	0.1

***Overall Objectives:** The goal of this proposal is to make fundamental advances in the processing, architected design, and electro-chemical-mechanical coupling of energy conversion materials that harvest mechanical energy, store it in energy dense chemicals, and release that energy in controlled mechanical motions.

***Statement of Potential Overlap:** no overlap.

***Proposal/Active Project Title:** Room temperature morphogenesis of metals

***Status of Support:** Current

Proposal/Award Number: FA9550-22-1-0095

***Source of Support:** AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 02/2022

***Proposal/Active Project End Date: (MM/YYYY):** 02/2025

***Total Anticipated Proposal/Project Amount:** $450,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** The goal of this proposal is to enable room temperature morphogenesis of metals by understanding how the material properties and healing ability of metals are influenced by morphology changes from electrochemical deposition and stripping.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Moore Inventor Fellow – James Pikul

***Status of Support:** Current

Proposal/Award Number: 9691

***Source of Support:** GORDON AND BETTY MOORE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2020

***Proposal/Active Project End Date: (MM/YYYY):** 11/2024

***Total Anticipated Proposal/Project Amount:** $675,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** The goal of this proposed work is to realize a soft robotic stomach that can power electronics by digesting high energy chemical sources in the environment, such as metals and glucose.

***Statement of Potential Overlap:** no overlap.

***Proposal/Active Project Title:** NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag) (PI: Cherie Kagan)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	0.5

***Overall Objectives:** Develop intelligent devices to monitor and control agricultural processes.

***Statement of Potential Overlap:** no overlap.

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.27
2027	0.26
2028	0.26
2029	0.15
2030	0.1

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas,

***Statement of Potential Overlap:** None – THIS PROPOSAL

***Proposal/Active Project Title:** Theme 2: Autonomous Materials through Physical Pathways (AMPP) Center

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2025

***Proposal/Active Project End Date: (MM/YYYY):** 05/2030

***Total Anticipated Proposal/Project Amount:** $0

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.1
2027	0.1

Year	Person Months
2028	0.1
2029	0.1
2030	0.1

***Overall Objectives:** To develop the next generation of scientific AI researchers, it is insufficient to develop algorithms without deep technical understanding of the processes that generate data. Our second philosophy is to produce a cohort of scientific AI researchers fluent in both foundational AI/ML and autonomous science.

***Statement of Potential Overlap:** no overlap.

***Proposal/Active Project Title:** Structure & Dynamics of Creep Deformation in Disordered Materials

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2027

***Total Anticipated Proposal/Project Amount:** $699,570

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.35
2026	0.35
2027	0.35

***Overall Objectives:** Provide a micro-structural understating of creep dynamics in disordered materials.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Arratia, Paulo in SciENcv on 2024-08-23 11:22:30

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Bidstrup Allen, Sue Ann

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: Chemical & Biomolecular Eng, Department, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.2
2025	0.2

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0,23
2027	0,23
2028	0,01
2029	0,01
2030	0,01

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None - THIS PROPOSAL

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Bidstrup Allen, Sue Ann in SciENcv on 2024-09-03 15:25:51

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Boyce, Ayesha

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0002-9509-8703

*POSITION TITLE: Associate Professor

*ORGANIZATION AND LOCATION: Arizona State University, Tempe, Arizona, United States

Proposals/Active Projects

***Proposal/Active Project Title:**	EvaluATE: The Evaluation Hub for Advanced Technological Education
***Status of Support:**	Current
Proposal/Award Number:	2332143
***Source of Support:**	Western Michigan University / National Science Foundation
***Primary Place of Performance:**	Arizona State University
***Proposal/Active Project Start Date: (MM/YYYY):**	08/2024
***Proposal/Active Project End Date: (MM/YYYY):**	12/2028
***Total Anticipated Proposal/Project Amount:**	$340,613

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.77
2025	0.77
2026	0.77
2027	0.77
2028	0.77

***Overall Objectives:** We will 1) Extend our current participatory action research case studies to understand how they enact and implement their DEI action plans (the second DATA); 2) Recruit and select two additional projects to work with us on participatory action research case studies and walk through the entire DATA-DATA model as we work with them to develop and implement DEI action plans, 3) Use our findings to develop evidence-informed DEI tool kits, 4) collect responses and reactions to the toolkits, and 5) continue to broadly disseminate project findings via webinar, website posts, blogs, conference presentations, and peer-reviewed manuscripts.

***Statement of Potential Overlap:** There is no overlap with other projects.

***Proposal/Active Project Title:**	SCALE Production Program – Microelectronics Workforce Development Project for Radiation Hardening
***Status of Support:**	Current
Proposal/Award Number:	13001218-137
***Source of Support:**	Purdue University/DOD-NAVY-NAVSEA: Naval Surface Warfare Cen
***Primary Place of Performance:**	Arizona State University
***Proposal/Active Project Start Date: (MM/YYYY):**	06/2024
***Proposal/Active Project End Date: (MM/YYYY):**	03/2027
***Total Anticipated Proposal/Project Amount:**	$525,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.08

***Overall Objectives:** The goal of the SCALE program is to produce a more ready workforce to support the needs of the US Government agencies, including the Department of Defense, and the associated Defense Industrial Base.

***Statement of Potential Overlap:** There is no overlap with other projects.

***Proposal/Active Project Title:**	Evaluation of NSF STC for the Integration of Modern Optoelectronic Materials on Demand (IMOD) (Additional Funds Y3)
***Status of Support:**	Current
Proposal/Award Number:	FP00030786_Rev2
***Source of Support:**	University of Washington/National Science Foundation
***Primary Place of Performance:**	Arizona State University
***Proposal/Active Project Start Date: (MM/YYYY):**	10/2023
***Proposal/Active Project End Date: (MM/YYYY):**	09/2024
***Total Anticipated Proposal/Project Amount:**	$26,401

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.35

***Overall Objectives:** IMOD STC External Evaluation using VEE approach. The VEE approach, developed with National Science Foundation – Education and Human Resources support, defines high-quality STEM educational programming as that which effectively incorporates cutting-edge scientific content, strong instructional pedagogy, and sensitivity to diversity and equity issues.

***Statement of Potential Overlap:** There is no scientific overlap with other projects, or budgetary overlap with the above awarded project.

***Proposal/Active Project Title:**	Collaborative Research: Building Inclusivity and Racial Equity in Marine Science
***Status of Support:**	Current
Proposal/Award Number:	HU-230014
***Source of Support:**	Hampton University/National Science Foundation
***Primary Place of Performance:**	Arizona State University
***Proposal/Active Project Start Date: (MM/YYYY):**	07/2023
***Proposal/Active Project End Date: (MM/YYYY):**	07/2028
***Total Anticipated Proposal/Project Amount:**	$300,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.77
2024	0.77
2025	0.77
2026	0.77
2027	0.77

***Overall Objectives:** In close collaboration with the key personnel Dr. Boyce will develop a comprehensive Evaluation Plan for the racial equity project, participate in meetings, dissemination, and reporting.

***Statement of Potential Overlap:** There is no scientific or budgetary overlap with other projects.

***Proposal/Active Project Title:**	NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)
***Status of Support:**	Current
Proposal/Award Number:	585700
***Source of Support:**	University of Pennsylvania/National Science Foundation
***Primary Place of Performance:**	Arizona State University
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2022
***Proposal/Active Project End Date: (MM/YYYY):**	08/2025
***Total Anticipated Proposal/Project Amount:**	$150,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	1.02
2023	1.02
2024	1.02

***Overall Objectives:** Dr. Ayesha Boyce (Arizona State University) and associates from the ASU College of Education, will serve as the external evaluator and will obtain any IRB approvals necessary for their work.This evaluation will provide formative data to guide ERC improvement and summative assessment of ERC quality and impact.

***Statement of Potential Overlap:** There is no overlap with other projects.

***Proposal/Active Project Title:** EvaluATE Diversity Equity Inclusion Study

***Status of Support:** Current

Proposal/Award Number: 1841783

***Source of Support:** Western Michigan University/National Science Foundation

***Primary Place of Performance:** Arizona State University

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2022

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $143,612

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	1.27
2023	0.67

***Overall Objectives:** 1) Develop and evaluate (document learning and use) training modules for ATE evaluators and PIs in the areas of Culture, Diversity, Equity, and Inclusion. 2) Explore, evaluate, and conduct research on the particular contextual and cultural complexities of the implementation of these training modules through two reflective case studies 3) Disseminate findings through publications and presentations.

***Statement of Potential Overlap:** There is no scientific overlap with the proposed projects.

***Proposal/Active Project Title:** STC Center for the Integration of Modern Optoelectronic Materials on Demand (IMOD)

***Status of Support:** Current

Proposal/Award Number: UWSC13338 - BPO61317

***Source of Support:** University of Washington/National Science Foundation

***Primary Place of Performance:** Arizona State University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2021

***Proposal/Active Project End Date: (MM/YYYY):** 09/2026

***Total Anticipated Proposal/Project Amount:** $388,593

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0,77
2022	0,77
2023	0,77
2024	0,77
2025	0,77

***Overall Objectives:** IMOD STC External Evaluation using VEE approach. The VEE approach, developed with National Science Foundation – Education and Human Resources support, defines high-quality STEM educational programming as that which effectively incorporates cutting-edge scientific content, strong instructional pedagogy, and sensitivity to diversity and equity issues.

***Statement of Potential Overlap:** No scientific overlap with proposed projects.

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Pennsylvania/National Science Foundation

***Primary Place of Performance:** Arizona State University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $234,776

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.77
2026	0,77
2027	0,77
2028	0.77

Year	Person Months
2029	0.3

***Overall Objectives:** external evaluation of the IoT4Ag ERC

***Statement of Potential Overlap:** There is no budgetary or scientific overlap with other proposed projects or awards.

***Proposal/Active Project Title:** Next Generation Workforce for a Just and Sustainable Future (NRT:JSF): An Integrated Science, Engineering and Policy Approach

***Status of Support:** Pending

Proposal/Award Number: FP00044023

***Source of Support:** CU Boulder/NSF

***Primary Place of Performance:** ASU

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2025

***Proposal/Active Project End Date: (MM/YYYY):** 05/2030

***Total Anticipated Proposal/Project Amount:** $300,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.25
2026	0.25
2027	0.25
2028	0.25
2029	0.25
2030	0.25

***Overall Objectives:** An evaluation of the Next Generation Workforce for a Just and Sustainable Future NRT.

***Statement of Potential Overlap:** no overlap

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to,

18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729–3733 and 3802.

Certified by Boyce, Ayesha in SciENcv on 2024-09-06 19:18:16

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Brier, Robert

*POSITION TITLE: IoT4Ag Managing Director

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** NSF Engineering Research Center (ERC) for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Philadelphia, PA

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,008,099

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	12
2025	12

***Overall Objectives:** IoT4Ag aims to create and translate to practice Internet of Thing (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** There is no scientific overlap with other projects, or budgetary overlap with the above awarded project.

***Proposal/Active Project Title:** NSF Engineering Research Center (ERC) for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Philadelphia, PA

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	12
2027	12
2028	12
2029	9
2030	6

***Overall Objectives:** IoT4Ag aims to create and translate to practice Internet of Thing (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** None - THIS PROPOSAL

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Brier, Robert in SciENcv on 2024-08-22 13:55:58

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Buckmaster, Dennis

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0002-5586-141X

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Proposals/Active Projects

***Proposal/Active Project Title:** ACTION for climate smart agriculture (alliance to catalyze transition incentives through open networks)

***Status of Support:** Current

Proposal/Award Number: 23089109

***Source of Support:** Wolfe's Neck Center

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 03/2028

***Total Anticipated Proposal/Project Amount:** $378,500

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0,22
2024	0.22
2025	0,22
2026	0,22
2027	0.22
2028	0.22

***Overall Objectives:** Improve interoperability across data platforms in agriculture.

***Statement of Potential Overlap:** Potentially some application areas for data pipeline and interoperability addressed in IoT4Ag.

***Proposal/Active Project Title:** Improving Nitrogen Efficiency in Corn Production Systems with Data and Modeling

***Status of Support:** Current

Proposal/Award Number: 23112135

***Source of Support:** U. Minnesota (USDA/SARE)

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $14,901

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.18
2024	0.18
2025	0.18

***Overall Objectives:** Develop and disseminate a user-centric, model-based nitrogen decision tool for corn production

***Statement of Potential Overlap:** Direct application of this OPTICORN project to the IoT4Ag biophysical modeling projects involving corn.

***Proposal/Active Project Title:** CCRI: Planning-M: Midwest Pivot Array for Autonomous Agricultural Sensing at Scale

***Status of Support:** Current

Proposal/Award Number: 23013648

***Source of Support:** NSF

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $175,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.13
2024	0.13
2025	0.13

***Overall Objectives:** Design a rotary gantry system and evaluate potential participation by researchers across the country.

***Statement of Potential Overlap:** This pivot array would be a great IoT4Ag testbed.

***Proposal/Active Project Title:** Stakeholder-informed integrated video and data systems for improved dairy efficiency

***Status of Support:** Current

Proposal/Award Number: 23046107

***Source of Support:** USDA?NIFA

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2027

***Total Anticipated Proposal/Project Amount:** $1,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.22
2024	0.22
2025	0.22
2026	0.22
2027	0.22

***Overall Objectives:** Develop video systems for analytics on feeding and feed consumption then integrate this with other data flows in a dairy production system.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Data Science and Analytics for Precision Livestock Systems

***Status of Support:** Current

Proposal/Award Number: 20123319

***Source of Support:** USDA/NIFA

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2021

***Proposal/Active Project End Date: (MM/YYYY):** 07/2026

***Total Anticipated Proposal/Project Amount:** $241,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.18
2022	0.18
2023	0.18

Year	Person Months
2024	0.18
2025	0.18
2026	0.18

***Overall Objectives:** Support for National Needs Fellow grad students for precision livestock systems.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** DSABE: Graduate Training in Data Science for Agricultural and Biological Engineers

***Status of Support:** Current

Proposal/Award Number: 20123283

***Source of Support:** USDA/NIFA

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2026

***Total Anticipated Proposal/Project Amount:** $246,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.18
2022	0.18
2023	0.18
2024	0.18
2025	0.18
2026	0.18

***Overall Objectives:** National Needs Fellowships for graduate students in data science for ABE.

***Statement of Potential Overlap:** One student supported on this project is doing IoT4Ag AI/ML related work regarding data analytics and is involved with the SPRING (Solar Powered Remote IoT4Ag Network Gateway) deployments.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture

***Status of Support:** Current

Proposal/Award Number: 20013344

***Source of Support:** NSF

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,763,745

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2020	1.27
2021	1.27
2022	1.27
2023	1.27
2024	1.27

***Overall Objectives:** Develop and advance IoT technologies in agriculture.

***Statement of Potential Overlap:** Educational programming and outreach.

***Proposal/Active Project Title:** OATS Consortium

***Status of Support:** Current

Proposal/Award Number: 18090499

***Source of Support:** FFAR and industry

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 02/2018

***Proposal/Active Project End Date: (MM/YYYY):** 12/2075

***Total Anticipated Proposal/Project Amount:** $497,500

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Develop and promote open source technologies for agriculture.

***Statement of Potential Overlap:** Data pipeline design and analytics in agricultural contexts.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,533,527

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1.27
2026	1.27
2027	1.27
2028	1
2029	0.73

***Overall Objectives:** Develop and transfer technologies related to sensors, data pipeline, AI and other analytics to improve agricultural production systems,

***Statement of Potential Overlap:** This is the project being proposed,

***Proposal/Active Project Title:** Providing Digital Literacy for Agriculture Students in the Age of AI and Big Data

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Kentucky (NSF)

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2025

***Proposal/Active Project End Date: (MM/YYYY):** 05/2028

***Total Anticipated Proposal/Project Amount:** $384,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.22
2026	0.22
2027	0.22
2028	0.22

***Overall Objectives:** Develop instructional content for degree and non-degree educational programming

related to digital agriculture including AI.

***Statement of Potential Overlap:** This is the proposed work.

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Buckmaster, Dennis in SciENcv on 2024-09-04 09:36:05

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors. Follow this format for each person.

*NAME: Cappelleri, David

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Development of a Mobile Microrobotic System for Targeted Drug Delivery for Brain Cancer

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Purdue Institute for Cancer Research

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2024

***Proposal/Active Project End Date: (MM/YYYY):** 07/2025

***Total Anticipated Proposal/Project Amount:** $50,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,18

***Overall Objectives:** The goal of this proposal is to develop a microrobotic system for targeted delivery of custom-therapeutics with long retention times and customizable release profiles in the brain for the treatment of cancer.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** CCRI: Planning-M: Midwest Pivot Array - Cyberinfrastructure for Autonomous Agricultural Sensing at Scale

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Purdue University, West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $175,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0,13
2024	0,13

***Overall Objectives:** The goal of this proposal is to plan for a CCRI full proposal on the instrumentation for an novel pivot array gantry system for field-scale agricultural sensing and interventions.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** NRI: Mobile Microrobots for Precision Medicine

***Status of Support:** Current

Proposal/Award Number: 96143

***Source of Support:** National Institutes of Health

***Primary Place of Performance:** Purdue University, West Lafayette

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2022

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $1,499,507

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	1,23
2024	1,23
2025	1,23

***Overall Objectives:** The goal of this proposal is to develop a microrobotic system for targeted delivery of custom-therapeutics with long retention times and customizable release profiles in the GI tract for the treatment of IBD-induced inflammation

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: 580247

***Source of Support:** NSF / University of Pennsylvania subcontract

***Primary Place of Performance:** Purdue University, West Lafayette

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,763,745

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	1.27
2022	1.27
2023	1.27
2024	1.27
2025	1.27

***Overall Objectives:** The goal of this project is to create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** Resilient ExtraTerrestrial Habitats

***Status of Support:** Current

Proposal/Award Number: 80NSSC19K1076

***Source of Support:** NASA

***Primary Place of Performance:** Purdue University, West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2019

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $15,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	1
2022	1
2023	1
2024	1
2025	0.18

***Overall Objectives:** The goal of this institute is to develop and demonstrate transformative smart autonomous habitats and related technologies that will adapt, absorb and rapidly recover from expected and

unexpected disruptions to deep space habitat systems without fundamental changes in function or sacrifices in safety. Key to this is the using of autonomous robots for maintenance and repair tasks under a variety of manned and unmanned configurations of the habitat.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** National Science Foundation / UPenn subcontract

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,533,527

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1.27
2027	1.27
2028	1.27
2029	1
2030	0.73

***Overall Objectives:** The goal of this project is to create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** None. This proposal.

***Proposal/Active Project Title:** Development of a Mobile Microrobotic System for Targeted Diagnostics and Drug Delivery for Ovarian Cancer

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Department of Defense

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2025

***Proposal/Active Project End Date: (MM/YYYY):** 05/2027

***Total Anticipated Proposal/Project Amount:** $439,240

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1

***Overall Objectives:** The goal is to develop a novel integrated mobile microrobot system consisting of a new class of adaptive swimming magnetic mobile microrobots and a combined imaging/actuation system for diagnostic and therapeutic precision medicine applications in the female reproductive tract.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** Development of a Mobile Microrobotic System for the Treatment of Pediatric Brain Tumors

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Department of Defense

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2025

***Proposal/Active Project End Date: (MM/YYYY):** 05/2027

***Total Anticipated Proposal/Project Amount:** $630,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1

***Overall Objectives:** The goal of this proposal is to develop a microrobotic system for targeted delivery of custom-therapeutics with long retention times and customizable release profiles in the brain for the treatment of pediatric brain cancer.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** Purdue Interdisciplinary Cancer Research Training

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** National Institutes of Health / NCI

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 12/2029

***Total Anticipated Proposal/Project Amount:** $2,132,595

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18
2026	0.18
2027	0.18
2028	0.18
2029	0.18

***Overall Objectives:** The goal of this project is to establish a training program to prepare a new generation of cancer researchers who think innovatively across scientific domains. The Purdue Interdisciplinary Cancer Research Training (PICRT), with a Dual-Title Ph.D. in Cancer Research, is designed to train Ph.D students to excel in team science and cancer research, as well as critical professional skills, such as grant writing, communication, and leadership to prepare trainees to effectively work with multidisciplinary teams that are necessary to accelerate cancer research, from basic discovery, and prevention to treatment.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** Lymphatic Preconditioning to Prevent Post-Injury Lymphedema

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Department of Defense / Subcontract

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2026

***Total Anticipated Proposal/Project Amount:** $111,377

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18
2026	0.18

***Overall Objectives:** The goal of this project is to investigate the design of a microrobot system to prevent post-injury lymphedema.

***Statement of Potential Overlap:** None,

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Cappelleri, David in SciENcv on 2024-08-16 15:28:05

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Carpin, Stefano

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0003-3837-7463

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of California, Merced, Merced, California, United States

Proposals/Active Projects

***Proposal/Active Project Title:** From Fields to Tables: Robotic Solutions for Sustainable Berry Harvesting
***Status of Support:** Current
Proposal/Award Number: N/A
***Source of Support:** University of California
***Primary Place of Performance:** UC Santa Cruz
***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024
***Proposal/Active Project End Date: (MM/YYYY):** 08/2026
***Total Anticipated Proposal/Project Amount:** $25,939

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,5
2026	0.5

***Overall Objectives:** This project aims at developing mechanized harvesters for berries in collaboration with industrial stakeholders located in Mexico.

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:** An Artificial Intelligent Irrigation System for Climate Resilient Agriculture
***Status of Support:** Current
Proposal/Award Number: N/A
***Source of Support:** University of California
***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $731,340

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	1

***Overall Objectives:** The goal of this project is to develop and test reinforcement learning algorithms to implement water recharge in California.

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:** Collaborative Research: FW-HTF-RL: Elevating Worker-Robot Collaborations in Agri-Food Ecosystems

***Status of Support:** Current

Proposal/Award Number: 2326310

***Source of Support:** NSF

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2027

***Total Anticipated Proposal/Project Amount:** $616,869

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	0.5
2026	0.5
2027	0.5

***Overall Objectives:** The project will advance fundamental understanding of the agricultural workforce and agricultural robotics and automation technology partnership in the context of future sustainable precision farming for fresh fruit tree-crop harvesting. The proposed research will help improve synergistic agricultural technology, worker and work outcomes.

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:** LACA: Labor and Automation in California Agriculture

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** University of California

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $3,100,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.1
2022	0.1
2023	0.1
2024	0.1

***Overall Objectives:** This project is building convergence research in sustainable agriculture and the future of farm work. It involves a collaboration between technology developers, human ecologists and labor experts, sustainability researchers, and farming organizations

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:** Mobile Robotic Lab for In-Situ Sampling and Management

***Status of Support:** Current

Proposal/Award Number: 2021-67022-33452

***Source of Support:** USDA/NIFA

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 11/2020

***Proposal/Active Project End Date: (MM/YYYY):** 10/2024

***Total Anticipated Proposal/Project Amount:** $474,732

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	1
2022	1
2023	1
2024	1

***Overall Objectives:** This project will develop the scientific and technoligcal foundations to create a new mobile robotics lab to perform sampling and analysis of water leaf potential at spatiotemporal scale not achievable with current technologies. The PIs will work on hardware and software co-design do novel actuators to autonomoulsy acquire and analyze speciments in the field

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:**	NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)
***Status of Support:**	Current
Proposal/Award Number:	1941529
***Source of Support:**	NSF/Penn
***Primary Place of Performance:**	Penn, UC Merced, Purdue, University of Florida
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2020
***Proposal/Active Project End Date: (MM/YYYY):**	08/2025
***Total Anticipated Proposal/Project Amount:**	$3,686,362

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	1
2022	1
2023	1
2024	1
2025	1

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** This is the phase one of the ERC grant, therefore the objectives are closely aligned with the current proposal.

***Proposal/Active Project Title:**	NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) (this proposal)
***Status of Support:**	Pending
Proposal/Award Number:	

***Source of Support:** NSF/Penn

***Primary Place of Performance:** Penn, UC Merced, Purdue, University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $4,214,111

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1.53
2027	1.5
2028	1.47
2029	1.01
2030	0.69

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** N/A

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Carpin, Stefano in SciENcv on 2024-08-14 11:22:02

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person,

*NAME: Chaudhari, Pratik

*POSITION TITLE: Assistant Professor

*ORGANIZATION AND LOCATION: Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** CPS: SMALL: NSF-MeitY: 5G Enabled Real-Time Digital Twins of Dynamic Construction Sites

***Status of Support:** Current

Proposal/Award Number: 2415249

***Source of Support:** NSF

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2027

***Total Anticipated Proposal/Project Amount:** $499,889

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.15
2026	0.15
2027	0.15

***Overall Objectives:** Develop multi-agent robotic and communication systems using unmanned aerial vehicles for autonomously mapping and understanding dynamic cluttered environments such as construction sites.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** AI Institute for Artificial and Natural Intelligence (ARNI)

***Status of Support:** Current

Proposal/Award Number: 2229929

***Source of Support:** Columbia University (NSF)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2028

***Total Anticipated Proposal/Project Amount:** $3,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.01
2026	0.01
2027	0.01
2028	0.01

***Overall Objectives:** This project will tackle the limitations and challenges of current learning systems, including learning with limited data, reasoning about causality and uncertainty, and lifelong learning, which are all hallmarks of biological systems, and will also extend the frontier of understanding how brains compute and learn.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Collaborative Research: RI: Medium: MoDL: Occam's Razor in Deep and Physical Learning

***Status of Support:** Current

Proposal/Award Number: CCF-2212519

***Source of Support:** NSF

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2026

***Total Anticipated Proposal/Project Amount:** $799,941

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.25
2025	0.2
2026	0.2

***Overall Objectives:** This proposal investigates how learning, in both artificial networks and physical networks, is effective because it creates simple representations of the input data.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Integrated quantum-inspired photonic solver (i-QIPS)

***Status of Support:** Current

Proposal/Award Number: FA8750-23-C-0539

***Source of Support:** DARPA

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2022

***Proposal/Active Project End Date: (MM/YYYY):** 10/2027

***Total Anticipated Proposal/Project Amount:** $7,248,911

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1
2025	1
2026	1
2027	1

***Overall Objectives:** Analysis, design, implementation, and benchmarking of an Integrated quantum-inspired photonic solver (i-QIPS) that can be utilized for efficient optimization of NP-hard problems.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Imaging the functional response of the lung to bronchoscopic lung volume reduction

***Status of Support:** Current

Proposal/Award Number: R01-HL159898-01A1

***Source of Support:** National Heart, Lung, and Blood Institute/NIH/DHHS

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2022

***Proposal/Active Project End Date: (MM/YYYY):** 07/2027

***Total Anticipated Proposal/Project Amount:** $2,673,063

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1,2
2025	1,2
2026	1,2
2027	1,2

***Overall Objectives:** Use functional lung imaging and inflammatory biomarkers to estimate the lung's response to bronchoscopic volumetric reduction as a treatemnt for late-stage emphysema.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** CAREER: Foundations of Small Data

***Status of Support:** Current

Proposal/Award Number: 2145164

***Source of Support:** NSF

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2022

***Proposal/Active Project End Date: (MM/YYYY):** 04/2027

***Total Anticipated Proposal/Project Amount:** $328,243

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.75
2026	0.75
2027	0.75

***Overall Objectives:** The goal of this proposal is to build a foundational understanding of learning tasks that cuts across the big, moderate and small data regimes. It seeks to understand why we can learn typical tasks efficiently, develop principles of how different learning tasks are related to each other and new methods for inference with very small sample sizes. It will apply these tools for accurate diagnosis of Alzheimer's Disease.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** An Information Geometric Understanding of Deep Learning

***Status of Support:** Current

Proposal/Award Number: N00014-22-1-2255

***Source of Support:** ONR

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2022

***Proposal/Active Project End Date: (MM/YYYY):** 03/2025

***Total Anticipated Proposal/Project Amount:** $405,845

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.75

***Overall Objectives:** This project seeks to develop an understanding of the optimization and generalization of deep neural networks using tools in information geometry.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NRI: Robotics, Science and Technology for Forestry

***Status of Support:** Current

Proposal/Award Number: 2022-67021-36856

***Source of Support:** USDA/NIFA

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2022

***Proposal/Active Project End Date: (MM/YYYY):** 02/2026

***Total Anticipated Proposal/Project Amount:** $1,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.15
2026	0.15

***Overall Objectives:** This project seeks to develop a sophisticated understanding of forests and the carbon ecosystem by building (a) detailed maps that can help understand a region as large as an entire forest and update these maps regularly to capture changes, (b) a fine-grained understanding of the geometry, semantics of the diverse vegetation inside the forest, and (c) develop new predictive models for understanding the diversity, health, and growth of a forest.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.25
2025	0.25

***Overall Objectives:** The IoT4Ag ERC aims to to create, and translate to practice, Internet of Things technologies and systems for precision agriculture. My group is working on developing aerial platforms for autonomous navigation in dense foliage using event- based cameras.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.1
2027	0.1
2028	0.1
2029	0.01
2030	0.01

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None – THIS PROPOSAL

***Proposal/Active Project Title:** Enhancing Model Calibration for Reliable Clinical Decision Making

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** NATIONAL INSTITUTES OF HEALTH

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2025

***Proposal/Active Project End Date: (MM/YYYY):** 03/2028

***Total Anticipated Proposal/Project Amount:** $599,740

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.1
2027	0.1
2028	0.1

***Overall Objectives:** The project aims to develop a comprehensive suite of methods for evaluating and enhancing the calibration of machine learning models, with a particular focus on neuroimaging applications.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** The Penn Fantastic Beasts Robot Arena

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** ONR

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2024

***Proposal/Active Project End Date: (MM/YYYY):** 11/2025

***Total Anticipated Proposal/Project Amount:** $266,075

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.01

***Overall Objectives:** The University of Pennsylvania (Penn) Fantastic Beasts Robot Arena is envisioned as an experimental facility that enables the study and physical experimentation of robots of different mobility, perceptual, and sensorimotor capabilities, e.g., flying, walking, crawling, driving, swimming, etc., in realistic environments.

***Statement of Potential Overlap:** None

In-Kind Contributions

***Status of Support:** Current

***Source of Support:** ARMY RESEARCH OFFICE

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 05/2022

***Summary of In-Kind Contribution:** Research Collaboration Agreement

***U.S. Dollar Value of In-Kind Contribution:** $0

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2025	0,1
2026	0.1
2027	0.1

***Overall Objectives:** Build theoretical and algorithmic tools for multi-robot agent team-forming with heterogeneous characteristics and abilities to operate in situations with changing environment and/or adversaries.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Chaudhari, Pratik in SciENcv on 2024-08-23 09:51:39

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Crawford, Melba

*POSITION TITLE: Professor of Civil Engineering, Electrical Engineering, and Agronomy

*ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Proposals/Active Projects

***Proposal/Active Project Title:** CCRI: Planning-M: Midwest Pivot Array for Autonomous Agricultural Sensing at Scale

***Status of Support:** Current

Proposal/Award Number: 10002189

***Source of Support:** National Science Foundation

***Primary Place of Performance:** West Lafayette, Indiana

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $175,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0,15
2024	0,25

***Overall Objectives:** Develop initial design for a center pivot system for acquiring data from multiple sensing techologies

***Statement of Potential Overlap:** No overlap with other projects.

***Proposal/Active Project Title:** Promoting Economic Resilience and Sustainability of the Eastern US Forests (PERSEUS)

***Status of Support:** Current

Proposal/Award Number: 2023-68012-38992

***Source of Support:** USDA/ -Sustainable Agricultural Systems

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2023

***Proposal/Active Project End Date: (MM/YYYY):** 03/2028

***Total Anticipated Proposal/Project Amount:** $10,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0,43
2024	0,43
2025	0.43

***Overall Objectives:** Provide scientifically sound information, outreach, and educational opportunities that lay the foundation for a paradigm shift in forestry toward data-driven, AI-supported, forest management systems that increase both the provision of ecosystem services and operational efficiency under the uncertainty of climate change

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Knowledge Transfer For Robust GeoAI Across Space, Sensors And Time Via Active Deep Learning

***Status of Support:** Current

Proposal/Award Number: 22057725

***Source of Support:** U of Houston

***Primary Place of Performance:** W. Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2022

***Proposal/Active Project End Date: (MM/YYYY):** 01/2025

***Total Anticipated Proposal/Project Amount:** $274,749

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0,44
2023	0,44
2024	0,44

***Overall Objectives:** Development of AI-based algorithms for classification and prediction models based on multi-modality remote sensing data and simulations from generative adversarial networks.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Advancing Remote Sensing Of The Biogeochemical State Of Midwestern Inland Waters

***Status of Support:** Current

Proposal/Award Number: 22036372

***Source of Support:** NASA

***Primary Place of Performance:** W. Lafayette, Indiana

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2022

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $643,519

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.22
2023	0.22
2024	0.22

***Overall Objectives:** Combine physical modeling and hyperpectral sensing to monitor biogeochemical characteristics in inland lakes and rivers.

***Statement of Potential Overlap**: None

***Proposal/Active Project Title:** Utilizing High-Throughput Phenotyping Technologies To Explore Shifts In Hybrid Maize Productivity And Stress Tolerance

***Status of Support:** Current

Proposal/Award Number: 21112607

***Source of Support:** Bayer Corporation

***Primary Place of Performance:** W. Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $1,020,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.15
2022	0.15
2023	0.15
2024	0.15

***Overall Objectives:** Acquisition and processing of data over select hybrids to evaluate heat and drought tolerance in Indiana and Oklahoma environments.

***Statement of Potential Overlap:** Overlap with CIMMYT in terms of the overall goals, but in totally different regimes.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: 20013344

***Source of Support:** U of Pennsylvania

***Primary Place of Performance:** West Lafayette, IN

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,763,745

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	1.27
2022	1.27
2023	1.27
2024	1.27
2025	1.27

***Overall Objectives:** Development and implementation of new in-situ sensing technologies, remote sensing platforms, and algorithms for Agriculture

***Statement of Potential Overlap:** Builds on the historical work in ARPA-E (20035252), but focuses on development of more theoretical algorithms. Proposed DoE (101057) project will involve more extended generalization from controlled facilities to field experiments.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** U of Pennsylvania

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,533,527

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1,27
2027	1,27
2028	1.27
2029	1
2030	0,73

***Overall Objectives:** To develop advanced sensing technologies, move communications and energy utilization forward, and develop new applications for decision making.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Expeditions: NEXUS - Novel and Emerging computing methods for compleX Urban Systems

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** West Lafayette, Indiana

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 12/2032

***Total Anticipated Proposal/Project Amount:** $15,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1
2027	1
2028	1
2029	1
2030	1
2031	1

***Overall Objectives:** Develop research theory and applications necessary for integrating data, enabling modeling, and supporting planning and prediction in complex city systems

***Statement of Potential Overlap:** No overlap with other projects

***Proposal/Active Project Title:**	Frameworks: Cyberinfrastructure for Urban Tree Resilience and Environmental Equity (uTREE)
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	NSF
***Primary Place of Performance:**	Purdue
***Proposal/Active Project Start Date: (MM/YYYY):**	07/2024
***Proposal/Active Project End Date: (MM/YYYY):**	06/2029
***Total Anticipated Proposal/Project Amount:**	$4,998,044

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.22
2026	0.22
2027	0.22
2028	0.22

***Overall Objectives:** Develop cyberinfrastructure using spatio-temporal generative artificial intelligence approaches capable of determining highly accurate locations and species of urban tress in cities nationwide.

***Statement of Potential Overlap:** 10% overlap with Perseus

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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Certified by Crawford, Melba in SciENcv on 2024-09-03 16:19:50

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Ehsani, Reza J

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: Professor, Merced, California, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Developing A Mobile, Scalable Self-Powered Agrivoltaics System

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** UNIVERSITY OF CALIFORNIA OFFICE OF THE PRESIDENT - UCOP

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $699,956

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1
2025	0.2

***Overall Objectives:** The project has the following specific goals: 1- Developing a prototype of a mobile agrivoltaics system. 2- Provide sustainable energy for the system and other electrical equipment in the field. 3- Demonstrate the benefits of mobile agrivoltaics systems in dual land use to growers and others involved in the industry through field demonstration

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Development of a Nondestructive Device for Real-time Monitoring of Plant Water Status

***Status of Support:** Current

Proposal/Award Number: 2022-77040-37625

***Source of Support:** UCOP

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $49,900

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** This project aims to develop a device to predict plant water status for efficient irrigation scheduling, Tree crop growers and crop consultants can use this cost-effective device for efficient irrigation scheduling.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Adapting Pistachio Production to a Changing Climate

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA-SCRI

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2022

***Proposal/Active Project End Date: (MM/YYYY):** 08/2026

***Total Anticipated Proposal/Project Amount:** $359,949

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.05
2023	0.1
2024	0.1
2025	0.1
2026	0.1

***Overall Objectives:** The engineering goal of this project that I am responsible to do is to develop a yield monitoring system for pistachio harvesting machines

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Integrated education programs to train students for a future in the agricultural and food industry

***Status of Support:** Current

Proposal/Award Number: 2022-77040-37625

***Source of Support:** USDA-HSI

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2022

***Proposal/Active Project End Date: (MM/YYYY):** 07/2026

***Total Anticipated Proposal/Project Amount:** $999,983

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.1
2023	0.2
2024	0.2
2025	0.2
2026	0.1

***Overall Objectives:** Our goal is to develop an educational pathway for current students and future food and ag workers to take advantage of the educational continuum from elementary to university and to enhance student adaptation to new technologies. Our specific goals are: • To attract students into agriculture and the food industry by developing educational outreach materials using novel technologies that strengthen the appeal of ag-related careers. • To provide educators with authentic career tools and hands-on educational materials to teach the future workforce and help students to better adapt to technology. • To mentor and encourage students to consider the educational continuum (from high school to community colleges, undergraduate universities to graduate school) to fulfill their potential.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Agricultural AI for Transforming Workforce and Decision Support (AgAID)

***Status of Support:** Current

Proposal/Award Number: 139743 SPC003192

***Source of Support:** USDA

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2021

***Proposal/Active Project End Date: (MM/YYYY):** 08/2026

***Total Anticipated Proposal/Project Amount:** $20,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.1

Year	Person Months
2022	0.1
2023	0.1
2024	0.1
2025	0.1

***Overall Objectives:** This project aims to develop and apply innovative AI-based tools and techniques that increase the productivity of labor in the agriculture domain. My contribution is to develop an AI-based model that predicts the best shaking frequency for optimum fruit removal when harvesting pistachio trees.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Developing Mechanical Harvesting of Table Olives (Olea europeae L.) in California and Israel

***Status of Support:** Current

Proposal/Award Number: US-5335-21

***Source of Support:** US-ISRAEL BINATIONAL AGRICULTURAL RESEARCH AND DEVELOP

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $139,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.1
2022	0.2
2023	0.2
2024	0.2

***Overall Objectives:** Design, fabrication, and field testing of a new harvesting machine for table olives using a new fruit removal system

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: 580247

***Source of Support:** NSF/Penn

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $3,705,736

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2020	1.2
2021	1.2
2022	1.2
2023	1.2
2024	1.2

***Overall Objectives:** The overall goal is to develop IoT solutions operating in the distinct agricultural environments of tree and row crops. The specific project I am involved in is developing a sensor to predict water stress in tree crops and its application in irrigation scheduling.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NSF/Penn

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $4,214,111

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1,53
2027	1.5
2028	1.47
2029	1.01
2030	0.49

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing

technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	Harvesting Platforms to Reduce Labor Cost and Labor Dependance in Fresh Market Tomato Production
***Status of Support:**	Pending
Proposal/Award Number:	2022-77040-37625
***Source of Support:**	CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE - SCMP
***Primary Place of Performance:**	UC Merced
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2024
***Proposal/Active Project End Date: (MM/YYYY):**	08/2026
***Total Anticipated Proposal/Project Amount:**	$999,900

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.2
2025	0.5
2026	0.2

***Overall Objectives:** This project aims to develop innovative, first-of-its-kind robotic harvesters for fresh market tomatoes. One robotic platform is for BPS tomatoes in CA, while the other is for PPS tomatoes in Florida, and both states are the leading fresh market tomato producers in the US. The long-term objective of the research is to enhance the profitability for growers and sustain the US fresh market tomato industry, enabled by salient features such as comparable speed and accuracy of the robotic harvesters to human pickers.

***Statement of Potential Overlap:** none

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

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Certified by Ehsani, Reza in SciENcv on 2024-07-17 12:27:05

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Field, Kristin

*POSITION TITLE: Director of Education and Inclusivity

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** CRISES: Center Consortium on Global Climate Risks and Resilient Childhoods

***Status of Support:** Current

Proposal/Award Number: 2437386

***Source of Support:** NSF

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $99,970

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,1

***Overall Objectives:** Develop plans to a) identify metrics for assessing childhood vulnerability and resilience to environmental and climatic risks, b) identify adaptation and mitigation strategies to promote resilience in children's lives and contexts; c) sustain interdisciplinary and inter-school collaboration and outreach to potential stakeholders.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precisision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	8,5
2025	12

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. I serve as the Director of Education and Inclusivity. I work in the areas of Engineering Workforce Development, Diversity and Culture of Inclusion and serve on the leadership team.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center (ERC) for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	12
2027	12
2028	12
2029	9
2030	6

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. I serve as the Director of Education and Inclusivity. I work in the areas of Engineering Workforce Development, Diversity and Culture of Inclusion and serve on the leadership team.

***Statement of Potential Overlap:** None - THIS PROPOSAL

Certification:

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Certified by Field, Kristin in SciENcv on 2024-08-26 15:29:59

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Hestir, Erin

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0002-4673-5745

*POSITION TITLE: Associate Professor

*ORGANIZATION AND LOCATION: University of California Merced, Merced, California, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Earth observations to combat invasive aquatic vegetation

***Status of Support:** Current

Proposal/Award Number: 80NSSC23K1563

***Source of Support:** National Aeronautics and Space Administration

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 10/2027

***Total Anticipated Proposal/Project Amount:** $799,998

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,1
2025	0.1
2026	0,1
2027	0,1

***Overall Objectives:** This proposed work will advance operational remote-sensing based monitoring program for community-level submerged aquatic vegetation (SAV) and genus-level floating aquatic vegetation (FAV) and modeling tools to enable the Bay Delta management community to assess the effect of previous management actions on IAV and forecast the effects of future actions to inform multi-agency decision making in the Bay Delta

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** COEQWAL: Equitable stewardship of California's water in a changing climate

***Status of Support:** Current

Proposal/Award Number: 00011511

***Source of Support:** UNIVERSITY OF CALIFORNIA OFFICE OF THE PRESIDENT - UCOP

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $552,948

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	0.5

***Overall Objectives:** To ensure a healthy water future for all, California needs water planning tools that are inclusive and equitable. This is the focus of COEQWAL, a COllaboratory for EQuity in Water ALlocations. In collaboration with a broad set of partnering communities with diverse water needs, our research team is developing accessible, online tools to inform our water future. Our goal is to open water planning tools and knowledge to the diverse water users of California.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Aquawatch Australia - California

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Commonwealth Scientific and Industrial Research Organization

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2022

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $179,410

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.08
2023	0.08

***Overall Objectives:** The AquaWatch system proposes to link in-situ sensing, water quality modelling and Earth Observations data and analytics to deliver real-time information to support monitoring and managing the health of inland, coastal, freshwater and marine aquatic environments and water resources

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** From 2D-3D: Leveraging space-based sensors to track water depth and volume in wetlands of the Central Valley of California

***Status of Support:** Current

Proposal/Award Number: 80NSSC22K0935

***Source of Support:** National Aeronautics and Space Administration

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2022

***Proposal/Active Project End Date: (MM/YYYY):** 03/2025

***Total Anticipated Proposal/Project Amount:** $449,449

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.08
2023	0.08
2024	0.08

***Overall Objectives:** We propose a Category 1 project that will take a multi-sensor, multi-scale approach to assess water resources, using a combination of ground, UAV, and satellite data. This project will test the sufficiency of multiple remote sensing datasets and demonstrate the utility of NASA and other Earth observations to estimate water depth and volume in order to guide managers developing wetland water budgets for decision-making and monitoring as part of GSPs.

***Statement of Potential Overlap**: None

***Proposal/Active Project Title:** Wildfire Impacts on Watershed Transport of Carbon to Coasts

***Status of Support:** Current

Proposal/Award Number: 80NSSC21K1655

***Source of Support:** National Aeronautics and Space Administration

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2021

***Proposal/Active Project End Date: (MM/YYYY):** 07/2025

***Total Anticipated Proposal/Project Amount:** $702,960

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.02
2022	0.02

Year	Person Months
2023	0.02
2024	0.02
2025	0.02

***Overall Objectives:** We propose to use remote sensing to assess the effects of wildfire-driven disturbances of carbon and sediment on kelp forests in the California Current System. This research will contribute to understanding local drivers of carbon and sediment transport and advance modeling capabilities for future coastal ecosystems' responses to climate change.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Labor and Automation in California Agriculture (LACA): Equity, Productivity & Resilience

***Status of Support:** Current

Proposal/Award Number: M21PR3417

***Source of Support:** University of California, Office of the President

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $3,102,383

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.08
2022	0.08
2023	0.08
2024	0.08

***Overall Objectives:** California is an agriculturally diverse and productive state, and yet its food system is vulnerable to climate change, regulatory change, water availability, and unexpected disturbances. Agricultural workforce shortages are also negatively affecting our food system. The proposed Labor and Automation in California Agriculture team is an interdisciplinary group spanning 4 UC campuses and UC ANR that is striving for transdisciplinary outcomes. Partnering with farmers, workers and agriculturalists, LACA's goal is to create a new model for agricultural technology, the Ag-Tech-Labor, that is farmer- and worker-friendly, while enhancing productivity and environmental sustainability.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for "Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC–1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $3,693,236

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2020	0,08
2021	0.08
2022	0.08
2023	0,08
2024	0,08

***Overall Objectives:** To ensure food, energy, and water security by advancing technology to increase crop production, while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. IoT4Ag unites faculty and students from the University of Pennsylvania, Purdue University, the University of California Merced, and the University of Florida with industry and government partners to transform agriculture

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Biodiversity Survey of the Cape (BioSCape)

***Status of Support:** Current

Proposal/Award Number: 80NSSC21K0086

***Source of Support:** National Aeronautics and Space Administration

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2020

***Proposal/Active Project End Date: (MM/YYYY):** 10/2025

***Total Anticipated Proposal/Project Amount:** $118,485

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2020	0,08
2021	0.08

Year	Person Months
2022	0.08
2023	0.08
2024	0.08

***Overall Objectives:** The primary objective for the proposed field campaign is to understand the structure, function, and composition of the region's ecosystems, and learn about how and why they are changing in time and space. The campaign is organized around three major themes aimed at understanding: 1) the distribution and abundance of biodiversity, 2) the role of biodiversity in ecosystem function, and 3) the impacts of biodiversity change on ecosystem services,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of California Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $4,214,111

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1.53
2027	1.5
2028	1.47
2029	1.01
2030	0.49

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Self-organizing Biodiversity Across Scales

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** National Aeronautics and Space Administration

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2025

***Proposal/Active Project End Date: (MM/YYYY):** 04/2028

***Total Anticipated Proposal/Project Amount:** $45,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5
2026	0.5
2027	0.5

***Overall Objectives:** We will investigate how biodiversity self-organizes across scales using the watershed as an organizing unit for life. Our proposal expands the Functional Process Zone (FPZ) concept, suggesting that watershed biodiversity is organized along hydrogeomorphologically-defined reach-to-valley units. Using a rich existing eDNA dataset from two California watersheds and building on data from two BioSCape watersheds in South Africa, we will examine the correspondence between FPZs and biodiversity as measured from DNA to space. This work will offer an innovative open framework for considering scales in watershed management globally by harmonizing remote sensing functional and hydrogeomorphological data with eDNA data.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Shorebird Habitat on the Amazon River: Dynamic Biodiversity Support Across Space and Time

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** National Aeronautics and Space Administration

***Primary Place of Performance:** Merced, CA

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2025

***Proposal/Active Project End Date: (MM/YYYY):** 04/2028

***Total Anticipated Proposal/Project Amount:** $75,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1

Year	Person Months
2026	1
2027	1

***Overall Objectives:** We propose to examine riverine dry-down and its effects on migratory shorebirds in one of the world's largest and most dynamic river systems: the Amazon River of South America. Critically, we will develop methods to study rapid habitat transitions, using multiresolution satellite observations and observations of shorebirds that occupy the riparian zone.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Intro the Aquaverse: Linking In Situ and Remote Sensing to Improve Synoptic Water Quality Monitoring and Harmful Algal Bloom Detection in the Delta

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** California Sea Grant

***Primary Place of Performance:** UC Merced

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2025

***Proposal/Active Project End Date: (MM/YYYY):** 03/2028

***Total Anticipated Proposal/Project Amount:** $384,488

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1
2027	1

***Overall Objectives:** Managing landscapes over broad scales presents unique challenges, but access to accurate, synoptic, near-real time information enhances situational understanding for resource and ecosystem managers, thereby facilitating decision making and outcome assessment. Remote sensing data has been increasingly integrated into routine water quality monitoring efforts in inland and coastal waters over the last decade allowing both researchers and water managers to use data on a landscape-wide scale for decision making. Highly variable and complex managed systems like the Delta pose unique challenges for remote sensing model validation, often requiring local model tuning. This study will develop the first roadmap for building truly integrated monitoring that assesses water quality conditions across the entire Delta on a near-real time basis in order to enable more comprehensive management tools. The aim of this proposal is to develop the methods necessary to iteratively update and validate remote sensing retrieval models for estimating water quality parameters by integrating continuous in situ water quality measurements and near-real time remote sensing imagery. We propose a system that regularly ingests new field- and remote sensing measurements that add to the calibration-validation input dataset for machine learning models of turbidity, dissolved organic matter (DOM), and harmful algal bloom (HAB) related parameters such as chlorophyll.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	Engineering Research Center for Transformation of American Rubber through Domestic Innovation for Supply security: TARDIS
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	National Science Foundation
***Primary Place of Performance:**	The Ohio State University
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2024
***Proposal/Active Project End Date: (MM/YYYY):**	08/2029
***Total Anticipated Proposal/Project Amount:**	$1,888,429

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.01
2026	0.01
2027	0.01
2028	0.01
2029	0.01

***Overall Objectives:** TARDIS will continue natural diversity with genetic approaches and new crop production practices to produce commercially viable yields and invent extraction methods to produce high performance and consistent latex and rubber for processing.

***Statement of Potential Overlap:** None

In-Kind Contributions

***Status of Support:**	Pending
***Source of Support:**	UC Merced
***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):**	09/2024
***Summary of In-Kind Contribution:**	TARDIS In-Kind
***U.S. Dollar Value of In-Kind Contribution:**	$149,162

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2024	0.01

***Overall Objectives:** Required in-kind matching at 15%

***Statement of Potential Overlap:** Supports TARDIS Activity

***Status of Support:** Pending

***Source of Support:** UC Merced

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 09/2024

***Summary of In-Kind Contribution:** TARDIS Support

***U.S. Dollar Value of In-Kind Contribution:** $134,102

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2024	0,01

***Overall Objectives:** Includes direct costs and unrecovered IDC and 25% tuition and fees from Graduate Division.

***Statement of Potential Overlap:** Additional support for TARDIS

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Hestir, Erin in SciENcv on 2024-08-14 13:22:34

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person,

*NAME: Kagan, Cherie

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Partnership for Education and Advancement of Quantum and nano-Sciences (PEAQS)

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2030

***Total Anticipated Proposal/Project Amount:** $0

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,01
2026	0,01
2027	0,01
2028	0,01
2029	0,01
2030	0,01

***Overall Objectives:** A strong partnership between Fort Lewis College (FLC), Norfolk State University (NSU), and IMOD creates PEAQS (Partnership for Education and Advancement of Quantum and nano-Sciences). This collaboration continues and expands the education and research partnership with STROBE, a sunsetting STC, FLC (a non-tribal Native American Serving Institution), NSU (a member of the Historically Black Colleges and Universities), with IMOD (an NSF Science and Technology Center for Integration of Modern Optoelectronic Materials on Demand). A cross-institutional team works together to impact recruitment, retention, and graduation of a diverse cohort of students. The goals for PEAQS are to create a diverse and inclusive community that focuses on cutting edge material science that explores the multi-scale interplay of atomic and meso-scale structure with functionality; exciting applications that attract a diverse group to STEM; effective curricula and pathways that recruit and retain the best in STEM; and long-term assessment to improve our strategies and share best practices.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	Venture for Innovation in Self-assembly and integration of Optoelectronic Nanostructures (VISION)
***Status of Support:**	Current
Proposal/Award Number:	N/A
***Source of Support:**	National Science Foundation
***Primary Place of Performance:**	University of Pennsylvania
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2024
***Proposal/Active Project End Date: (MM/YYYY):**	08/2030
***Total Anticipated Proposal/Project Amount:**	$0

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.01
2026	0.01
2027	0.01
2028	0.01
2029	0.01
2030	0.01

***Overall Objectives:** We propose a partnership between UC Merced (UCM) and the NSF Science and Technology Center (STC) for Integration of Modern Optoelectronic Materials on Demand (IMOD) at the University of Washington (UW) to establish a research-education-workforce development economy via a PREM program entitled VISION: Venture for Innovation in Self-assembly and integration of Optoelectronic Nanostructures. Our materials-focused research program is symbiotic to IMOD's research and embraces a convergent research approach by inviting broad participation to pursue materials innovation towards scalable optoelectronics with integrated solid-state atom-like emitter assemblies for advancing quantum light generation and light manipulation. Along this research theme the specific objectives for the PREM program are: • Provide research opportunities for undergraduate students through summer programs and lab rotations, fostering hands-on learning and mentoring relationships. • Emphasize collaborative research, leadership, and team science in graduate training to mentor the next generation of scholars. • Equip K-14 educators and graduate students with tools and skills to teach modern materials science and engineering, sparking interest in STEM fields from an early age. • Introduce faculty mentors to culturally responsive mentoring practices for building an inclusive research and learning environment that will result in improved student advancement along the PREM Program.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	Center for Integration of Modern Optoelectronic Materials on Demand (IMOD)
***Status of Support:**	Current
Proposal/Award Number:	UWSC12986

***Source of Support:** UNIVERSITY OF WASHINGTON (NATIONAL SCIENCE FOUNDATION)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2021

***Proposal/Active Project End Date: (MM/YYYY):** 09/2024

***Total Anticipated Proposal/Project Amount:** $1,928,400

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,5

***Overall Objectives:** This proposal aims to explore colloidal semiconductor quantum dots as materials for conventional and quantum optoelectronic devices.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NNCI: Establishment of a Nanotechnology User Node at the University of Pennsylvania

***Status of Support:** Current

Proposal/Award Number: ECCS-2025608

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,200,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,1
2025	0.1

***Overall Objectives:** Our Goals for the next five years are (i) to continue to grow capacity to enable the mid-Atlantic nanotechnology community to realize their research goals and fulfill their educational needs; (ii) to help define future directions in nanotechnology through the synthesis, analysis, dissemination, and encouragement of the efforts of our community; (iii) to deepen education, outreach, and workforce development programs, providing nano literacy opportunities, hands-on access to tools and technologies, and experiential internship opportunities, that will develop a skilled, knowledgeable, and diverse nanotechnology workforce; and (iv) to assist our community through seed grant programs, proposal support, and leveraging regional incubator and investment resources, to translate research results into innovative, tangible products.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	6.5
2025	6.5

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	6.5
2027	6.5
2028	6.5
2029	6.5
2030	6.5

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None – THIS PROPOSAL

***Proposal/Active Project Title:** NQVL:QSTD:Pilot: Quantum systems for enhanced sensors and diagnostics (Q-SENSED)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 12/2025

***Total Anticipated Proposal/Project Amount:** $1,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5

***Overall Objectives:** This proposed pilot project aims to establish a National Quantum Virtual Laboratory to design, develop, and translate quantum sensing technologies into practical use.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Nano Solutions On-Chip (NSOC)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** DEPARTMENT OF ENERGY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2028

***Total Anticipated Proposal/Project Amount:** $250,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1
2026	0.1

Year	Person Months
2027	0.1
2028	0.1

***Overall Objectives:** This proposal aims to take advantage of solution-processable photonic and electronic building blocks, comprising colloidal 0D- & 1D semiconducting nanomaterials, to co-design materials and fabrication strategies that simultaneously meet demands for low-energy manufacture, Si-chip compatibility, novel interconnect strategies toward full "vertical 3D integration," and efficient and robust performance in extreme environments.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Kagan, Cherie in SciENcv on 2024-09-06 11:39:30

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors. Follow this format for each person.

*NAME: Krogmeier, James V.

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0001-7041-2113

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Proposals/Active Projects

***Proposal/Active Project Title:** SPR-4863: High Speed Deflectometer Study

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Indiana Department of Transportation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2026

***Total Anticipated Proposal/Project Amount:** $1,302,494

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.75
2026	0.75

***Overall Objectives:** Design, construct, and test a traffic speed deflectometer system for evaluating Indiana roadway pavements

***Statement of Potential Overlap:** Topic overlaps with the other INDOT projects but the specific tasks and deliverables are different

***Proposal/Active Project Title:** ACTION for Climate Smart Agriculture (Alliance to Catalyze Transition Incentives through Open Networks)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Wolfe's Neck Center

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 04/2028

***Total Anticipated Proposal/Project Amount:** $378,500

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0,05
2024	0,05
2025	0,05
2026	0,05
2027	0,05
2028	0,05

***Overall Objectives:** Create API and software to support Climate Smart Agriculture

***Statement of Potential Overlap:** There is no overlap with other current projects

***Proposal/Active Project Title:** SPR-4820: Enhanced Methods to Evaluate Pavement Stripping and Interface Bonding Condition Using 3D Ground Penetrating Radar and Falling Weight Deflectometer

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Indiana Department of Transportation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $223,450

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0,25
2024	0,74
2025	0,25

***Overall Objectives:** Integration of GPR and FWD data for pavement analysis

***Statement of Potential Overlap:** Topic is related to that of the other INDOT projects, but the specific tasks

and deliverables are different.

***Proposal/Active Project Title:** CCRI: Planning-M: Midwest Pivot Array for Autonomous Agricultural Sensing at Scale

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $175,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.27
2024	0.27
2025	0.05

***Overall Objectives:** Plan for the Midwest Pivot Array, a rotating center pivot gantry integrated with high-speed fiber networking and computing to create a shared field-scale platform for research.

***Statement of Potential Overlap:** Involves design of pivot gantry but not the purchase of the equipment

***Proposal/Active Project Title:** SPR-4713: Development of Guidelines for Compatible Sensor Installation, Data Collection, Database-based Visualization for INDOT

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Indiana Department of Transportation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2023

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $167,774

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.1

Year	Person Months
2024	0.1

***Overall Objectives:** Develop guidelines for roadway sensor deployment and data collection.

***Statement of Potential Overlap:** None.

***Proposal/Active Project Title:** GOALI: CNS Core: Medium: Communication-Computation Co-Design for Rural Connectivity and Intelligence under Nonuniformity: Modeling, Analysis, and Implementation

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation through University of Kansas

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $507,157

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.5
2024	0.46
2025	0.44

***Overall Objectives:** Establish methodologies for co-designing communication and computation resources in rural 5G-and-beyond network systems.

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:** ODF: National Agricultural Producers Data Cooperative: A Strategic Framework for Innovation

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** NIFA via University of Nebraska, Lincoln

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2024

***Total Anticipated Proposal/Project Amount:** $130,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0,04
2023	0,04
2024	0.04

***Overall Objectives:** Develop API frameworks for integration with the National Animal Germplasm Program.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Automated Record Keeping for Maintenance Operations via Tracking Maintenance Vehicles using the Parson's Telematics Tracks

***Status of Support:** Current

Proposal/Award Number: SPR-4605

***Source of Support:** Indiana Department of Transportation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2022

***Proposal/Active Project End Date: (MM/YYYY):** 04/2025

***Total Anticipated Proposal/Project Amount:** $151,998

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0,25
2023	0,25
2024	0,05

***Overall Objectives:** Develop recording keeping algorithm from GPS tracks

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: 20013344

***Source of Support:** NSF via University of Pennsylvania

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,763,745

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2020	0.05
2021	0.75
2022	0.75
2023	0.75
2024	0.75

***Overall Objectives:** Perform research on in-field wireless communications and long range wireless backhaul.

***Statement of Potential Overlap:** Both generally involve communications and experimental communication systems.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag Continuation)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Pennsylvania/National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,533,527

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1.27
2026	1.27
2027	1.27
2028	1

Year	Person Months
2029	0.73

***Overall Objectives:** Researching agricultural sensor and backhaul communications

***Statement of Potential Overlap:** This is the continuation of the NSF ERC grant. Complementary to remaining grants.

***Proposal/Active Project Title:** Hardening the economical acquisition of intersection data to improve system integrity (Grant 16100148)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Michigan

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $70,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1

***Overall Objectives:** Research traffic signal control technologies

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Krogmeier, James in SciENcv on 2024-08-19 06:46:57

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Love, David

*POSITION TITLE: Nick Trbovich Professor of ECE

*ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Consulting
***Status of Support:** Current
Proposal/Award Number:
***Source of Support:** Texas Instruments
***Primary Place of Performance:** Home
***Proposal/Active Project Start Date: (MM/YYYY):** 07/2024
***Proposal/Active Project End Date: (MM/YYYY):** 09/2024
***Total Anticipated Proposal/Project Amount:** $30,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.6

***Overall Objectives:** This is one day per week consulting to provide technical assistance on wireless standards to attorneys at TI. It is not research and not related to my research.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Lockheed Martin Disruption Project Scoping
***Status of Support:** Current
Proposal/Award Number:
***Source of Support:** Lockheed Martin
***Primary Place of Performance:** Purdue University
***Proposal/Active Project Start Date: (MM/YYYY):** 05/2024
***Proposal/Active Project End Date: (MM/YYYY):** 01/2025
***Total Anticipated Proposal/Project Amount:** $375,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.08

***Overall Objectives:** This is an effort by Lockheed to support collaboration with Purdue across a number of research areas, My portion is to support discussion of disruptive communication techniques that align with Lockheed's research mission.

***Statement of Potential Overlap:** Both involve advanced wireless techniques

***Proposal/Active Project Title:** Novel Array Processing for SatCom in Interference Channels

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** MIT Lincoln Labs

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 11/2023

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $109,998

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.76
2023	0.76

***Overall Objectives:** Develop novel satellite communication signal processing techniques.

***Statement of Potential Overlap:** Both involve wireless and beyond 5G communication.

***Proposal/Active Project Title:** NSF Convergence Accelerator Track G Combating Vulnerability and Unawareness in 5G Network Security

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Kansas/National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $661,673

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1
2025	0.22

***Overall Objectives:** Develop comprehensive security solution for 5G DoD systems.

***Statement of Potential Overlap:** Both involve new research for wireless communication. They are complementary.

***Proposal/Active Project Title:** CCRI: Planning-M: Midwest Pivot Array – Cyberinfrastructure for Autonomous Agricultural Sensing at Scale

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $175,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.13
2024	0.13

***Overall Objectives:** Develop plan to build a precision agriculture testbed equipment for advanced wireless and sensing experiments.

***Statement of Potential Overlap:** This project involves a novel testbed for use in agriculture. Both projects are complementary.

***Proposal/Active Project Title:** Collaborative Research: NSF-AoF: CNS Core: Small: Towards Scalable and AI-Based Solutions for Beyond 5G Radio Access Networks

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2023

***Proposal/Active Project End Date: (MM/YYYY):** 12/2025

***Total Anticipated Proposal/Project Amount:** $215,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.04
2024	0.04
2025	0.04

***Overall Objectives:** Develop signal processing and information theory techniques to enhance cell free massive MIMO networks.

***Statement of Potential Overlap:** Both involve advanced wireless techniques and are complementary.

***Proposal/Active Project Title:** GOALI: CNS Core: Medium: Communication-Computation Co-Design for Rural Connectivity and Intelligence under Nonuniformity: Modeling, Analysis, and Implementation

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation/University of Kansas

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $507,157

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.46
2024	0.46
2025	0.46

***Overall Objectives:** Develop new beyond-5G communication techniques for the rural use case.

***Statement of Potential Overlap:** Both involve wireless and beyong-5G ideas.

***Proposal/Active Project Title:** Streamlining and Securing AI Tensor Computations across Heterogeneous Edge Network Systems

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Purdue Univ. Autonomous and Connected Systems Funding

***Primary Place of Performance:** Purdue

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2022

***Proposal/Active Project End Date: (MM/YYYY):** 08/2024

***Total Anticipated Proposal/Project Amount:** $73,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.5
2024	0.5

***Overall Objectives:** This research will jointly design computation and communication techniques among edge devices in a manner that exploits the structure of tensors to create intelligent AI processing redundancies. Second, we will develop protocols for securingthe transmission and computation processes associated with the distributed tensor operations.

***Statement of Potential Overlap:** This project could involve wireless, and techniques developed might be complementary.

***Proposal/Active Project Title:** Network-Aware Distributed Machine Learning and Sensor Fusion for Spectrum System Intelligence

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Office of Naval Research

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2021

***Proposal/Active Project End Date: (MM/YYYY):** 05/2025

***Total Anticipated Proposal/Project Amount:** $1,557,472

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	1.45
2024	1.45
2025	1.45

***Overall Objectives:** Working on communications and signal processing with spectrum sensing and classification

***Statement of Potential Overlap:** This project involves wireless and beyond 5G systems, which could be complementary.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Pennsylvania/National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,763,745

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.77
2024	0.77
2025	0.77

***Overall Objectives:** Researching agricultural sensor and backhaul communications

***Statement of Potential Overlap:** This is the phase 1 of this project.

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Pennsylvania/National Science Foundation

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,533,527

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months

Year	Person Months
2025	1.27
2026	1.27
2027	1.27
2028	1.02
2029	0.73

***Overall Objectives:** This is the second phase of the NSF IoT4Ag ERC. We will be researching agricultural sensor and backhaul communications

***Statement of Potential Overlap:** This project,

***Proposal/Active Project Title:** 3FT: Functional, flexible fronthaul technology

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NTIA

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2024

***Proposal/Active Project End Date: (MM/YYYY):** 11/2029

***Total Anticipated Proposal/Project Amount:** $750,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	1.14
2026	0.57
2027	0.68
2028	0.19
2029	0.4

***Overall Objectives:** We will perform advanced research for new frontal technology. We will be researching techniques to reduce latency, expand the radio to fusion distance, and improve performance using new physical layer designs.

***Statement of Potential Overlap:** Both projects involve advanced wireless research. The use case is different, but techniques developed in both project could be complementary.

***Proposal/Active Project Title:** Integrated Sensing and Communication for Sixth Generation Mobile Cellular

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NTIA

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2028

***Total Anticipated Proposal/Project Amount:** $800,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.45
2026	0.45
2027	0.45
2028	0.45

***Overall Objectives:** Work on research for new integrated sensing and communications algorithms and analysis for 6G wireless,

***Statement of Potential Overlap:** This is complementary to the proposed research, This project involves integrated sensing and communications, which is important to new 6G applications like agriculture

In-Kind Contributions

***Status of Support:** Current

***Source of Support:** Samsung PhD Fellowships

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 08/2024

***Summary of In-Kind Contribution:** Fellowship funded Ph.D. student

***U.S. Dollar Value of In-Kind Contribution:** $75,000

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2024	0.04

***Overall Objectives:** Samsung grants students fellowships to pursue Ph.D. degrees. One student in this program has joined Purdue.

***Statement of Potential Overlap:** N/A

***Status of Support:** Current

***Source of Support:** Nokia

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 01/2024

***Summary of In-Kind Contribution:** Voluntary support

***U.S. Dollar Value of In-Kind Contribution:** $54,235

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2024	0,1

***Overall Objectives:** Voluntary support funding to support research on zero-to-low energy sensing for 6G

***Statement of Potential Overlap:** This would be complementary and would give us additional support for wireless research.

***Status of Support:** Current

***Source of Support:** Qualcomm

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 06/2024

***Summary of In-Kind Contribution:** Voluntary Support

***U.S. Dollar Value of In-Kind Contribution:** $75,000

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2024	0.1

***Overall Objectives:** Performa research on machine learning techniques for communications

***Statement of Potential Overlap:** This project would be complementary.

***Status of Support:** Pending

***Source of Support:** National Research Foundation of Korea

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 01/2025

***Summary of In-Kind Contribution:** Externally funded visiting scholar

***U.S. Dollar Value of In-Kind Contribution:** $33,375

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2025	0.04

***Overall Objectives:** Postdoctoral fellow who will work on 6G topics.

***Statement of Potential Overlap:** This would be complementary and extend Purdue's wireless research capabilities.

***Status of Support:** Pending

***Source of Support:** Nokia

***Receipt (or Anticipated Receipt) Date of In-Kind Contribution: (MM/YYYY):** 01/2025

***Summary of In-Kind Contribution:** Voluntary support

***U.S. Dollar Value of In-Kind Contribution:** $50,000

Person-Month(s) (or Partial Person-Months) Per Year Devoted to the In-Kind Contribution:

Year	Person Months
2025	0.1

***Overall Objectives:** Nokia may provide voluntary support for sustainabilities research.

***Statement of Potential Overlap:** This would be complementary and extend Purdue's precision agriculture 6G research

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Love, David in SciENcv on 2024-08-19 21:25:55

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Messina, Carlos

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Proposals/Active Projects

***Proposal/Active Project Title:** CERCA - Circular Economy that Reimagines Corn Agriculture. Maize adaptation to cold environments

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Foundation for Food and Agricultural Research

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2027

***Total Anticipated Proposal/Project Amount:** $386,161

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,12
2025	0.12
2026	0.12
2027	0,12

***Overall Objectives:** Develop an AI based prediction model to evaluate putative traits to grow corn in corn environments

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Harnessing biology and artificial intelligence to enable broccoli (Brassica oleracea var. italica) breeding in subtropical environments.

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Florida

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2024

***Proposal/Active Project End Date: (MM/YYYY):** 08/2027

***Total Anticipated Proposal/Project Amount:** $263,162

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.12
2026	0.12
2027	0.12

***Overall Objectives:** Develop a Hybrid AI dynamical modeling approach to predict genomic breeding values in broccoli

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** ICWRX

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** DOD

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $50,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.12

***Overall Objectives:** Develop prediction methods

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** CERCA - Circular Economy that Reimagines Corn Agriculture. Improve nitrogen use in maize.

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Foundation for Food and Agricultural Research

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2024

***Proposal/Active Project End Date: (MM/YYYY):** 05/2027

***Total Anticipated Proposal/Project Amount:** $419,800

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.12
2026	0.12
2027	0,12

***Overall Objectives:** Develop a novel crop growth model with abilities to simulate perennial traits in maize driven by gene networks and effects from ancient relatives

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** Genes, Software, and a Playbook: Combating HLB in Florida Orchards

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Citrus Research & Development Foundation

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2024

***Proposal/Active Project End Date: (MM/YYYY):** 02/2026

***Total Anticipated Proposal/Project Amount:** $999,563

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,12
2026	0.12

***Overall Objectives:** Develop solutions to HLB (citrus greening) including genes, and evaluation methodologies.

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** Climate Resilient Cereals Innovational Lab

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USAID

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2029

***Total Anticipated Proposal/Project Amount:** $991,963

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.24
2025	0.24
2026	0.24
2027	0.24
2028	0.24
2029	0.24

***Overall Objectives:** Develop and build capacity in modeling approaches to accelerate genetic gain in cereals in Africa

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** UF Presidential Strategic Funding: UF/IFAS Crop Transformation Center

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Florida

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $2,006,536

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	3
2025	3

***Overall Objectives:** Organize a Crop Transformation Center that implements a concept-to-product approach to deliver solutions to Farmers,

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:**	NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)(THIS PROPOSAL)
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	University of Pennsylvania (NSF is prime)
***Primary Place of Performance:**	University of Florida
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2025
***Proposal/Active Project End Date: (MM/YYYY):**	08/2030
***Total Anticipated Proposal/Project Amount:**	$5,691,522

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1
2027	1
2028	1
2029	0,75
2030	0.65

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:**	Breeding technologies to enable equitable access to locally adapted broccoli
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	Foundation for Food and Agricultural Research
***Primary Place of Performance:**	University of Florida
***Proposal/Active Project Start Date: (MM/YYYY):**	07/2025
***Proposal/Active Project End Date: (MM/YYYY):**	06/2029

***Total Anticipated Proposal/Project Amount:** $500,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.12
2027	0.12
2028	0.12
2029	0.12

***Overall Objectives:** Develop improved cultivars of broccoli and methods

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** Unfolding innovative research and teaching methods at FVSU in understanding sorghum-aphid interactions through advanced breeding tools

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** USDA-NIFA

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2025

***Proposal/Active Project End Date: (MM/YYYY):** 03/2027

***Total Anticipated Proposal/Project Amount:** $30,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.05
2027	0.05

***Overall Objectives:** Create a NEXUS for student collaboration between University of Florida and Fort Valley State University

***Statement of Potential Overlap:** none

***Proposal/Active Project Title:** SP: Rapid Selection of HLB Resistance Genes to Fast Track Citrus Variety Development

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** USDA-SCRI

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2027

***Total Anticipated Proposal/Project Amount:** $1,499,139

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.12
2026	0.12
2027	0.12

***Overall Objectives:** Develop screening methods and gene solutions to HLB

***Statement of Potential Overlap:** none

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Messina, Carlos in SciENcv on 2024-08-23 10:55:09

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Olsson, Roy H

*POSITION TITLE: Associate Professor

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Tribo-Electric Antennas for Longwaves (TEAL)
***Status of Support:** Current
Proposal/Award Number: N/A
***Source of Support:** DRAPER (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)
***Primary Place of Performance:** University of Pennsylvania
***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024
***Proposal/Active Project End Date: (MM/YYYY):** 09/2025
***Total Anticipated Proposal/Project Amount:** $180,123

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,75

***Overall Objectives:** Create a longwave antenna based on Triboelectric generators

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Compact Wide-band Frequency Agile Microwave Filters for WARCHAMP Phase 1
***Status of Support:** Current
Proposal/Award Number: WARCHAMP PHASE I
***Source of Support:** NEXTFLEX (DEPARTMENT OF THE AIR FORCE)
***Primary Place of Performance:** University of Pennsylvania
***Proposal/Active Project Start Date: (MM/YYYY):** 05/2024
***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $759,388

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1

***Overall Objectives:** We envision creating a 4x4 planar panel of tunable magnetic bias circuits and high selectivity Yttrium Iron Garnet (YIG) filters on a Ku-band lattice spacing, This will enable every element in a digital phased array to have a high performance tunable bandpass, bandstop, or bandpass/bandstop combination filter that is tunable from 2-18 GHz,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Monolithically Integrated III-V Materials for High Temperature Pressure Sensors

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** SANDIA (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 01/2027

***Total Anticipated Proposal/Project Amount:** $508,624

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5
2026	0.5
2027	0.25

***Overall Objectives:** Create a pressure sensor and readout electronics capable of operation at 500 degrees centigrade,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** All-Optical Control of Isolated High Voltage Power Systems Using Integrated Electronic, Photonic, and Microfabricated Sensing and Breaker Technology

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** ADVANCED RESEARCH PROJECTS AGENCY-ENERGY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2023

***Proposal/Active Project End Date: (MM/YYYY):** 11/2026

***Total Anticipated Proposal/Project Amount:** $2,620,244

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,1
2025	0.1
2026	0.1

***Overall Objectives:** This project aims to develop a heterogeneous chiplet platform that integrates high-speed gatedriving, optical power delivery and signal isolation, and non-invasive remote sensing andprotection for utilizing next-generation wide bandgap (WBG) and ultra-wide bandgap (UWBG) power devices,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Strategic Poling of Ferroelectric Films for Reconfigurable Sensors, Resonators, and Actuators

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** SANDIA NATIONAL LABORATORY (DEPARTMENT OF ENERGY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2026

***Total Anticipated Proposal/Project Amount:** $84,919

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,1
2025	0.1
2026	0,1

***Overall Objectives:** To utilize strategic poling of ferroelectric materials to boost the performance of piezoelectric sensors and actuators.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** REconfigurable Single ChiP RadiO FrequeNcy Signal ProcEssor (RESPONSE)

***Status of Support:** Current

Proposal/Award Number: 732224

***Source of Support:** University of Arizona (DEFENSE ADVANCED RESEARCH PROJECTS AG

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $99,445

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1

***Overall Objectives:** This project will create an Acoustoelectric RF front end transceiver.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Low Voltage MoS2/AlScN FE-FETs

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** INTEL CORPORATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2023

***Proposal/Active Project End Date: (MM/YYYY):** 07/2025

***Total Anticipated Proposal/Project Amount:** $450,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.2
2025	0.2

***Overall Objectives:** Realize low switching voltage MoS2/AlScN FE-FETs for electronic memory.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** H6 Tactical-Grade Clock

***Status of Support:** Current

Proposal/Award Number: CW2085888

***Source of Support:** INTEL FEDERAL LLC (DARPA)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2023

***Proposal/Active Project End Date: (MM/YYYY):** 03/2028

***Total Anticipated Proposal/Project Amount:** $1,290,573

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1
2027	1
2028	1

***Overall Objectives:** The proposed project will design, fabricate and measure Aluminum Nitride (AlN) MEMS resonator arrays with exceptional thermal and vibration stability. The resonators will be integrated with electronic circuits at Intel to form oscillators, The oscillator arrays will be used with advanced signal processing to achieve small, low power clocks with exceptional timing stability.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Acoustoelectric Amplifiers for Efficient Radio Frequency Signal Processing

***Status of Support:** Current

Proposal/Award Number: S-215-020-004

***Source of Support:** UES, INC. (DEPARTMENT OF THE AIR FORCE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2022

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $180,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** This project is exploring the implementation of AE amplifiers and their combination with multiferroic materials.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Advancement of Bulk Acoustic Wave Devices using Strategically Poled Acoustic Resonators (SPAR)

***Status of Support:** Current

Proposal/Award Number: 2424695

***Source of Support:** SANDIA NATIONAL LABORATORY (DEPARTMENT OF ENERGY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2024

***Total Anticipated Proposal/Project Amount:** $80,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** Realize acoustic resonators and filters exploiting the strategic poling of aluminum scandium nitride materials to unlock performance regimes not possible utilizing heterogeneous materials.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Advanced Magnetics for Power Supplies

***Status of Support:** Current

Proposal/Award Number: DEFENSEWERX AGREEMENT

***Source of Support:** DEFENSEWERX

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2022

***Proposal/Active Project End Date: (MM/YYYY):** 07/2025

***Total Anticipated Proposal/Project Amount:** $425,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1

***Overall Objectives:** Using nano fabrication techniques to create high performance magnetic cores for compact power supplies.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** High-band Operation via Periodic Structures (HOPS)

***Status of Support:** Current

Proposal/Award Number: SUB TO HR0011221-9-0037

***Source of Support:** AKOUSTIS (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2022

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $1,191,755

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	0.5

***Overall Objectives:** This project explores scaling of miniature acoustic filter technology to X and Ku Band frequencies.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Collaborative Hierarchical and Agile Responsive Materials (CHARM)

***Status of Support:** Current

Proposal/Award Number: 940002

***Source of Support:** DREXEL UNIVERSITY (ARMY RESEARCH OFFICE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2021

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $1,496,501

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1

***Overall Objectives:** This program is studying innovations in active materials towards material needs expressed by the US Army.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Aluminum Scandium Nitride MEMS PDK

***Status of Support:** Current

Proposal/Award Number: SUB TO HR0011-21-9-0004

***Source of Support:** AKOUSTIS (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $290,096

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.2

***Overall Objectives:** This project is developing a process design kit including the material properties of AlScN to enable multi-project design and fabrication of AlScN MEMS devices.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Magnetostatic Wave Filters with Multiferroic Frequency Tuning

***Status of Support:** Current

Proposal/Award Number: FA8650-21-1-7010

***Source of Support:** DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 02/2021

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $3,243,935

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1.5

***Overall Objectives:** This project is developing 2-18 GHz tunable high-Q filters based on magnetostatic wave resonators.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Wideband Integrated Photonic-Acoustic signal Cancellation (WiPAC)

***Status of Support:** Current

Proposal/Award Number: FA8650-21-1-7011

***Source of Support:** DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 02/2021

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $2,885,065

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1

***Overall Objectives:** This project is developing a wideband RF canceller based on electro-acoustic-optic signal processing

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** This is an engineering research center exploring the sensors, networks, and data analytics needed for precision agriculture.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** CAREER: Doped Aluminum Nitride Ferroelectric Microelectromechanical Systems

***Status of Support:** Current

Proposal/Award Number: 1944248

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 02/2020

***Proposal/Active Project End Date: (MM/YYYY):** 01/2025

***Total Anticipated Proposal/Project Amount:** $500,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,3

***Overall Objectives:** Studying the periodic poling of AlScN materials through both the film thickness and laterally across the film. The periodic poling is utilized to selectively excite high order overtone acoustic resonances that enable dramatic frequency scaling of acoustic resonators without the steep reductions in resonator performance of prior frequency scaling attempts.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Electromechanical Components for Efficient, Small Scale Power Conversion and Energy Harvesting

***Status of Support:** Current

Proposal/Award Number: 2019-19090900002

***Source of Support:** CENTRAL INTELLIGENCE AGENCY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 12/2019

***Proposal/Active Project End Date: (MM/YYYY):** 11/2024

***Total Anticipated Proposal/Project Amount:** $495,016

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,5

***Overall Objectives:** The project is exploring the use of resonant electromechanical and magneto-electromechanical systems for DC-DC power converters and magnetic energy harvesting.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0,5
2027	0.48
2028	0.47
2029	0,3
2030	0,15

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas,

***Statement of Potential Overlap:** This proposal is an extension of EEC-1941529

***Proposal/Active Project Title:** AROMA - ADVANCED INFRASTRUCTURE FOR NEXT GEN MICROWAVE RADIO

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** AKOUSTIS (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $165,279

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,1
2026	0.2

***Overall Objectives:** Penn proposes to theoretically and experimentally study the power handling and linearity limits of P3F AlScN filters within the context of the commercial requirements. This includes study of harmonic generation (e.g. H2), intermodulation distortion (e.g. IIP3), linear power handling (e.g. P1dB) and lifetime. Emphasis will be placed on identifying both the limits and the underlying mechanisms limiting linear operation at high power. Based on its findings, Penn shall recommend any needed changes to the filter architecture or P3F resonator film stack to meet commercial requirements.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	Best of All World Architecture for Array Front Ends, BAWA-AFE
***Status of Support:**	Pending
Proposal/Award Number:	N/A
***Source of Support:**	OTAVA (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)
***Primary Place of Performance:**	University of Pennsylvania
***Proposal/Active Project Start Date: (MM/YYYY):**	01/2025
***Proposal/Active Project End Date: (MM/YYYY):**	06/2026
***Total Anticipated Proposal/Project Amount:**	$297,278

***** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.3
2026	0.6

***Overall Objectives:** Penn will collaborate with Otava to design filters leveraging the tight integration of Akoustis P3F XBAW technology with SOI CMOS. Penn will contribute to the filter design and the coupled electromagnetic and acoustic modeling essential for realizing the desired filter responses in fabricated hardware. Penn will also assist in characterizing the filter linearity and in designing filters for enhanced linearity. Univ of Penn will study the IIP3, P1dB, and H2 limits of the coupled P3F XBAW/SOI CMOS reconfigurable filters.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	COFFEE MIMOSA Proposal
***Status of Support:**	Pending
Proposal/Award Number:	N/A
***Source of Support:**	RAYTHEON COMPANY (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)
***Primary Place of Performance:**	University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $187,564

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,25
2026	0,25

***Overall Objectives:** Specifically, UPenn will study methods to suppress spurious responses in BAW filters constructed from periodically poled piezoelectric films (P3F). Upenn will study methods to tailor the P3F layer stack to strongly emphasize the desired operating mode while suppressing under/over mode resonances that compromise the stop band rejection in certain frequency bands. Penn will also explore filter level synthesis techniques to further reject the spurious responses, A secondary goal will be to tailor the layer stack and filter designs to suppress nonlinear harmonics generated by the filters at high power.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** COmpact Front-end Filters at the ElEment-level (COFFEE) Technical Area 2 (TA2)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** NORTHROP GRUMMAN (DARPA)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $371,809

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,5
2026	0.5

***Overall Objectives:** Penn shall design, model, and test filters realized in periodically poled piezoelectric films. Penn will study the mechanisms limiting filter linearity and long term reliability.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** LADDER – a giant Leap AheaD in DEsigning Rf filters

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** AKOUSTIS (DEPARTMENT OF DEFENSE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2024

***Proposal/Active Project End Date: (MM/YYYY):** 06/2027

***Total Anticipated Proposal/Project Amount:** $375,002

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5
2026	0.5
2027	0.5

***Overall Objectives:** To construct a scalable (in both geometry and frequency) model of XBAW/XP3F resonators for integration into LADDER, allowing non-experts to predict the nonlinear response of filters realized in the Akoustis XBAW/XP3F process.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** XBAW P3F Resonators for High Power S-Band Filters (XPRESSO)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** AKOUSTIS (DEFENSE ADVANCED RESEARCH PROJECTS AGENCY)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024

***Proposal/Active Project End Date: (MM/YYYY):** 06/2027

***Total Anticipated Proposal/Project Amount:** $125,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.01
2026	0.01
2027	0.01

***Overall Objectives:** To design and grow periodically polarized piezoelectric film (P3F) AlScN resonators.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Ferroelectric Resonator Based Intrinsically Switched Multiplexers (FORESEE)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** AKOUSTIS / OFFICE OF NAVAL RESEARCH

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2024

***Proposal/Active Project End Date: (MM/YYYY):** 03/2027

***Total Anticipated Proposal/Project Amount:** $330,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1
2026	0.1
2027	0.1

***Overall Objectives:** To collaborate with Akoustis to develop a ferroelectric bulk acoustic wave (BAW) resonator based all-acoustic intrinsically switched multiplexer (ISM) for the 2-40 GHz spectrum.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** HIGH ENERGY PHYSICS RESEARCH AT THE UNIVERSITY OF PENNSYLVANIA

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** OFFICE OF SCIENCE/DEPARTMENT OF ENERGY

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2024

***Proposal/Active Project End Date: (MM/YYYY):** 03/2027

***Total Anticipated Proposal/Project Amount:** $646,224

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1
2026	0.1
2027	0.1

***Overall Objectives:** To research sensors and circuits for high energy physics experiments.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Ferroelectric Aluminum Scandium Nitride Memory Devices and Integration at Elevated Temperatures (FAST)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** NEXTFLEX (DEPARTMENT OF THE AIR FORCE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $250,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** The purpose of this program is to solve critical fundamental and practical challenges in the use of ferroelectric AlScN for nonvolatile memory operating at elevated temperatures (> 500 °C). AlScN is of interest to the US Air Force for potential use in ferrocapacitive (FE-cap) memory elements capable of operating at high temperatures.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Research and Development of Electronic Materials for DAF Applications

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** UES, INC. (DEPARTMENT OF THE AIR FORCE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2023

***Proposal/Active Project End Date: (MM/YYYY):** 07/2026

***Total Anticipated Proposal/Project Amount:** $749,995

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1
2026	0.1

***Overall Objectives:** Penn's collaborative program with AFRL will pursue development of 1. Non-Volatile RF switches with high figure of merit (FoM). 2. Scalable synthesis and integration of 2D/3D semiconductor heterostructures for low-power digital switches and memory devices.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Research within the Optoelectronic Blueprint for Emergent Sensing Systems (ROBERSS)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** UES, INC. (DEPARTMENT OF THE AIR FORCE)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2023

***Proposal/Active Project End Date: (MM/YYYY):** 07/2026

***Total Anticipated Proposal/Project Amount:** $749,995

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1
2026	0.1

***Overall Objectives:** Penn's collaborative program with AFRL will pursue development of 1. Light generation in the mid-IR via AlScN integrated on Si photonic platform. 2. Light modulation and detection via exciton-polaritons in 2D Mo and W chalcogenide heterostructures and superlattices.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Olsson, Roy in SciENcv on 2024-08-27 07:19:49

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors. Follow this format for each person.

*NAME: Quinn, Daniel

*POSITION TITLE: Assistant Professor

*ORGANIZATION AND LOCATION: Purdue University, West Lafayette, Indiana, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Corn Response to Experimental Biological Seed Treatments

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Bayer Crop Science

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $15,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Assess corn response to experimental seed treatments.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Corn Response to Seed Orientation and Orientation Ratio

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** John Deere

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2024

***Proposal/Active Project End Date: (MM/YYYY):** 01/2025

***Total Anticipated Proposal/Project Amount:** $87,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Assess corn response to seed orientation placement and orientation ratio at planting.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Evaluation of Nitrification and Urease Inhibitors with Injected UAN + ATS for Corn Production

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Koch

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $27,600

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Assess corn response to enhanced efficiency fertilizers and nitrogen fertilizer rates.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Democratizing Geospatial Data Science for Agricultural Producers Project Description

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Nebraska-Lincoln

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2024

***Proposal/Active Project End Date: (MM/YYYY):** 10/2024

***Total Anticipated Proposal/Project Amount:** $54,600

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months

Year	Person Months
2024	0.18

***Overall Objectives:** Assessing corn spatial response to applied nitrogen fertilizer rates.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Purdue On The Farm: Boots on the Ground
***Status of Support:** Current
Proposal/Award Number:
***Source of Support:** Indiana Soybean Alliance
***Primary Place of Performance:** Purdue University
***Proposal/Active Project Start Date: (MM/YYYY):** 03/2024
***Proposal/Active Project End Date: (MM/YYYY):** 02/2025
***Total Anticipated Proposal/Project Amount:** $50,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Establish and build an on-farm research and extension program in Indiana.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** SSC Nitrogen Rate by Density WO 13
***Status of Support:** Current
Proposal/Award Number:
***Source of Support:** Bayer Crop Science
***Primary Place of Performance:** Purdue University
***Proposal/Active Project Start Date: (MM/YYYY):** 03/2024
***Proposal/Active Project End Date: (MM/YYYY):** 03/2025
***Total Anticipated Proposal/Project Amount:** $18,900

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Assess short-stature corn response to seeding and nitrogen fertilizer rates.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Corn Yield, Nitrogen Use, and Biological Activity Response to Asymbiotic N-Fixing Microbial Amendments

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Indiana Corn Marketing Council

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $90,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Assess corn response to nitrogen fertilizer rate and asymbiotic N fixing biological products.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** FY24 Identifying Agronomic Strategies and Tools that Mitigate Corn Yield Losses Due to Tar Spot, Year 2.

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Indiana Corn Marketing Council

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $50,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.18

***Overall Objectives:** Assess corn response to fungicide applications

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Quantifying Popcorn (Zea mays Everta L.) Nitrogen Fertilizer Optimum Rate and Use Efficiency Differences in Comparison to Field Dent Corn (Zea mays L.)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** The Popcorn Board

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2023

***Proposal/Active Project End Date: (MM/YYYY):** 03/2025

***Total Anticipated Proposal/Project Amount:** $110,182

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.18
2024	0.18

***Overall Objectives:** Assess Popcorn Response to Nitrogen Fertilizer Rates.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Less is more: Eco-intensification using recycled drainage water for fertigation.

***Status of Support:** Current

Proposal/Award Number: 2022-67019-36414

***Source of Support:** USDA-NIFA

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2022

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $749,959

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.35
2023	0.35
2024	0.35

***Overall Objectives:** Assess corn response to sub-surface drainage.

***Statement of Potential Overlap:** No Overlap

***Proposal/Active Project Title:** Improving the Economic and Ecological Sustainability of US Crop Production through On-Farm Precision Experimentation

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Illinois

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2021

***Proposal/Active Project End Date: (MM/YYYY):** 10/2024

***Total Anticipated Proposal/Project Amount:** $104,559

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.18
2022	0.18
2023	0.18

***Overall Objectives:** Assessing corn response to variable nitrogen and seeding rate on-farm research trials.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,763,745

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	1.27
2022	1.27
2023	1.27
2024	1.27
2025	1.27

***Overall Objectives:** Testbed leader for field research projects involving IoT4Ag sensor development and testing.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	NSF Engineering Research Center for Internet of Things for Precision Agriculture (IoT4Ag)
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	NSF
***Primary Place of Performance:**	Purdue University
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2025
***Proposal/Active Project End Date: (MM/YYYY):**	08/2030
***Total Anticipated Proposal/Project Amount:**	$5,533,527

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1.27
2026	1.27
2027	1.27
2028	1
2029	0.73

***Overall Objectives:** Sensor development and testbed establishment for the establishment of IoT in agriculture.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:**	INSPIRE-ag: Incentivizing Nitrogen Savings and Policy Integration for Reducing Emissions for agroecosystems
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	University of Illinois
***Primary Place of Performance:**	Purdue University
***Proposal/Active Project Start Date: (MM/YYYY):**	04/2025
***Proposal/Active Project End Date: (MM/YYYY):**	03/2030
***Total Anticipated Proposal/Project Amount:**	$1,331,300

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.43
2026	0.43
2027	0.43
2028	0.43
2029	0.43

***Overall Objectives:** Assessing corn response to reduced nitrogen fertilizer rates to drive future recommendations, emission reductions, and policy decisions,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Identifying Production and Environmental Factors Associated with Disease and Mycotoxin Contamination to Mitigate Loss in Indiana Corn

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Indiana Corn Marketing Council

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 12/2025

***Total Anticipated Proposal/Project Amount:** $100,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18

***Overall Objectives:** Assess corn disease and ear rot response to cultural and chemical management practices,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Integrating New Data Intensive Farm Management (DIFM) Tools for Assessing Spatial Seed and N Fertilizer Management in Corn

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Indiana Corn Marketing Council

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 12/2025

***Total Anticipated Proposal/Project Amount:** $70,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18

***Overall Objectives:** Assess corn response to variable rate nitrogen fertilizer and seeding rate using on-farm research trials.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** The Feasibility of Winter Hardy Legumes in the North Central Region

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Minnesota

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 11/2024

***Proposal/Active Project End Date: (MM/YYYY):** 10/2027

***Total Anticipated Proposal/Project Amount:** $250,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18
2026	0.18
2027	0.18

***Overall Objectives:** Assess the performance and establishment of legume cover crops in corn and soybean production systems.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Digging Deeper into the Novel Short-Stature Corn: Assessing Belowground Root Performance, Soil Microbial Interactions, and Soil Carbon Sequestration

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Indiana Corn Marketing Council

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $65,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18

***Overall Objectives:** Assess short-stature corn root development and soil carbon sequestration potential.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Establishing a partnership for long-term, field-scale Resilient Agriculture test beds at Purdue farms

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** Indiana Corn Marketing Council

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2025

***Total Anticipated Proposal/Project Amount:** $10,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.18

***Overall Objectives:** Establishment of long-term sustainable research trials at Purdue University research farms across Indiana.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Cultivating Resilience: Advancing Cover Crop Integration into Corn and Soybean Production Systems

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NRCS

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2024

***Proposal/Active Project End Date: (MM/YYYY):** 07/2029

***Total Anticipated Proposal/Project Amount:** $2,116,630

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.43

***Overall Objectives:** Assess corn and soybean performance in diverse cover crop and fertility management systems,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Accurate Assessment of Corn Nitrogen Status with High Spatial-spectral Proximal Sensing

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** NRCS

***Primary Place of Performance:** Purdue University

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024

***Proposal/Active Project End Date: (MM/YYYY):** 05/2026

***Total Anticipated Proposal/Project Amount:** $418,381

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	2.23
2025	2.23
2026	2.23

***Overall Objectives:** Assess corn plant nitrogen content using a LeafSpec sensor,

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete, This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Quinn, Daniel in SciENcv on 2024-09-04 06:59:55

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Small, Ian M

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0001-5406-3486

*POSITION TITLE: Associate Professor

*ORGANIZATION AND LOCATION: University of Florida, Quincy, Florida, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Development of a disease and yield loss model for foliar diseases of cotton

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Cotton Inc

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $25,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0,36

***Overall Objectives:** Development of a disease and yield loss model for foliar diseases of cotton

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Integrated management of tomato spotted wilt, leaf spot, rust, white mold, and CBR in peanut

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Peanut Board

***Primary Place of Performance:** Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $13,425

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.12

***Overall Objectives:** Investigate management strategies for economically important diseases of peanut

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Managing Peanut Leaf Spot & Fungicide Resistance with Crop Diversity, Sensor Detection Tools, and Predictive Models

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Peanut Board

***Primary Place of Performance:** Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $22,400

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.12
2025	0.12

***Overall Objectives:** To evaluate approaches to manage leaf spot of peanut.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Regional project to address cotton diseases

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Cotton Inc

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2024

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $25,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.36

***Overall Objectives:** Regional project to evaluate management strategies for foliar cotton diseases.

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Inspire-Instruct-Equip-Empower

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA NIFA

***Primary Place of Performance:** Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 10/2026

***Total Anticipated Proposal/Project Amount:** $750,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.12
2025	0.12
2026	0.12

***Overall Objectives:** Developing tech-savvy youth advocates in agriculture through engaging 4H youth in agricultural technology

***Statement of Potential Overlap:** There is no overlap between current and proposed project

***Proposal/Active Project Title:** Nitrogen savings through a decision support framework for FL cropping systems

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Florida Dept. of Ag and Consumer Services

***Primary Place of Performance:** Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2023

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $730,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.12
2025	0.12
2026	0.12

***Overall Objectives:** Enhancing environmental and economic outcomes of best management practices related to row crop nitrogen fertilization

***Statement of Potential Overlap:** There will be no overlap between current and proposed project

***Proposal/Active Project Title:** Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** NSF

***Primary Place of Performance:** Quincy, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $5,128,586

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	2
2025	2

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come

***Statement of Potential Overlap:** No overlap.

***Proposal/Active Project Title:** Southeast Partnership for Advanced Renewables from Carinata

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA NIFA

***Primary Place of Performance:** University of Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2017

***Proposal/Active Project End Date: (MM/YYYY):** 07/2025

***Total Anticipated Proposal/Project Amount:** $14,810,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1.2
2025	1

***Overall Objectives:** To conduct research, teaching and extension to support the commercialization of Brassica carinata in the southeast US.

***Statement of Potential Overlap**: No potential overlap since this project will end before the proposed project begins.

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Pennsylvania (NSF is prime)

***Primary Place of Performance:** Quincy, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,691,522

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1
2027	1
2028	1
2029	0,75
2030	0.65

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Plant Pathology PhD Graduate Education: Innovative Data Science and AI Training

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** USDA NIFA

***Primary Place of Performance:** Quincy, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2029

***Total Anticipated Proposal/Project Amount:** $238,500

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1
2026	0.1
2027	0.1
2028	0.1
2029	0.1

***Overall Objectives:** To develop an innovative data science and AI training curriculum and experiential learning (research/extension) plan for PhD students in Plant Pathology.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** CARINATA-Southern Energy and Ecosystem Diversification System-S.E.E.D.S

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** DOE-EERE

***Primary Place of Performance:** Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2025

***Proposal/Active Project End Date: (MM/YYYY):** 06/2031

***Total Anticipated Proposal/Project Amount:** $9,793,384

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	2
2026	2
2027	2

Year	Person Months
2028	2
2029	2
2030	1

***Overall Objectives:** Enabling commercialization of intermediate crop carinata as a sustainable, low carbon intense feedstock for sustainable aviation fuel

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Conservation Hub for the Economic Empowerment of Rural Stakeholders

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** USDA NIFA

***Primary Place of Performance:** Florida

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2024

***Proposal/Active Project End Date: (MM/YYYY):** 09/2029

***Total Anticipated Proposal/Project Amount:** $9,989,887

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.12
2026	0.12
2027	0.12
2028	0.12
2029	0.12

***Overall Objectives:** Bringing stakeholders along the value chain to make winter cover crop production and/or integrated crop-livestock systems economically viable for all stakeholders in the value chain

***Statement of Potential Overlap**: No overlap

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

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18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729–3733 and 3802.

Certified by Small, Ian in SciENcv on 2024-08-12 20:40:34

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Stofer, Kathryn

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0002-3659-490x

*POSITION TITLE: Research Associate Professor

*ORGANIZATION AND LOCATION: University of Florida, Gainesville, Florida, United States

Proposals/Active Projects

***Proposal/Active Project Title:** HCC:Medium:Optimizing Interactive Machine Learning Tools to Support Plant Scientists using Human Centered Design

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2026

***Total Anticipated Proposal/Project Amount:** $1,199,053

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.1
2024	0.5
2025	0.5
2026	0.4

***Overall Objectives:** This project will use a human-centered approach to design natural and effective labeling interfaces that (a) balance problem and machine learning performance with decreased effort for the human labeler(s) and (b) also generalize across domains, but especially in domains with large quantities of image data like plant science.

***Statement of Potential Overlap:** Stofer may use contacts with Florida 4-H on other funded efforts to help recruit youth to this project. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** TEAMIIStat

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** NASA via Orlando Science Center

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2022

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $79,998

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.5
2023	1
2024	1
2025	0.5

***Overall Objectives:** Evaluation of Orlando Science Cente Engineering Education afterschool program for elementary schoolers.

***Statement of Potential Overlap:** None. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** UF Health Cancer Center Community Engagement Research

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** UF Health Cancer Center

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2022

***Proposal/Active Project End Date: (MM/YYYY):** 06/2026

***Total Anticipated Proposal/Project Amount:** $92,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	1.2
2023	2.4
2024	1.8
2025	0.5

***Overall Objectives:** Support the UF Health Cancer Community Engagement efforts and Center Citizen Scientist program specifically through developing and researching programs to promote cancer research and

build trust in the community served by the Center.

***Statement of Potential Overlap:** None. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** Work Ready Florida

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA NIFA FANE

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2022

***Proposal/Active Project End Date: (MM/YYYY):** 12/2025

***Total Anticipated Proposal/Project Amount:** $750,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	0.6
2023	1
2024	1
2025	0.6

***Overall Objectives:** WRF will create virtual 4-H clubs designed to prepare youth for agricultural certifications. Stofer is project evaluator.

***Statement of Potential Overlap:** No artificial intelligence or human-centered computing is included in the certification curricula. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** EXCITE

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** Extension Foundation

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2021

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $124,976

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months

Year	Person Months
2021	3.6
2022	4.8
2023	3.75
2024	3
2025	1.5

***Overall Objectives:** Promote immunization confidence among rural and medically underserved audiences. Increase knowledge about and acceptability of COVID-19, flu, and other adult immunizations,Document barriers to vaccine confidence and vaccine access and effective interventions to eliminate these barriers.Increase connection and communication between priority populations and healthcare systems.Increase accessibility of vaccination clinics to priority populations.

***Statement of Potential Overlap:** None. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** A Proof-of-Concept for the Agricultural Literacy Certification Program (ALCP)

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA NIFA - Subaward from Utah State University

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $4,076

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.18
2024	0.18

***Overall Objectives:** 1) develop a research-based online agricultural literacy certification program, 2) demonstrate educator gains in agricultural knowledge and career awareness, 3) measure educator self-efficacy for using agriculture as a context for their academic content, and 4) identifying participant planned behaviors for including agricultural instruction as context for their academic content.

***Statement of Potential Overlap:** None. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** CCDAAL - Collaborative Curriculum Design for Authentic Agriscience Literacy

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA NIFA

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 01/2021

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $300,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	0.2
2022	0.75
2023	1.44
2024	0.75

***Overall Objectives:** 1. Design, conduct, and evaluate a high school teacher professional development program involving collaborative curriculum design for authentic agriscience topics while incorporating an equity framework. 2. Design, conduct, and evaluate high school teacher professional development led by teachers from Obj. 1 to share lessons developed in Obj. 1 with more teachers.

***Statement of Potential Overlap:** None. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** Community Engagement for IoT4Ag Center

***Status of Support:** Current

Proposal/Award Number: EEC- 1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2023	0.9
2024	0.6

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** N/A

***Proposal/Active Project Title:** Determining Antecedents to Consumer Acceptance of Gene Editing Technology

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** USDA NIFA

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 10/2019

***Proposal/Active Project End Date: (MM/YYYY):** 12/2024

***Total Anticipated Proposal/Project Amount:** $121,078

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2019	0.2
2020	1.2
2021	1.2
2022	1
2023	0.12
2024	0.12

***Overall Objectives:** 1) define consumer preferences for regulation and consumption of food derived from gene-edited crops 2) determine the most effective way to communicate about gene-editing technology to effect consumer intentions to change behavior, No cost extension in 2023,

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Evaluation of the UF Health Cancer Center Education programs

***Status of Support:** Current

Proposal/Award Number:

***Source of Support:** University of Florida Health Cancer Center

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 07/2019

***Proposal/Active Project End Date: (MM/YYYY):** 06/2025

***Total Anticipated Proposal/Project Amount:** $44,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2019	1.8
2020	1.8
2021	1.8
2022	1.5
2023	1.2
2024	1.2
2025	1.2

***Overall Objectives:** Design and conduct quantitative evaluations of UF Health Cancer Center programs for undergraduate students, teachers, and post-baccalaureate scholars

***Statement of Potential Overlap:** none. Stofer is funded 100% on soft money.

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag) (THIS PROPOSAL)

***Status of Support:** Pending

Proposal/Award Number:

***Source of Support:** University of Pennsylvania

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $5,691,522

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	0.5
2027	0.5
2028	0.5
2029	0.5
2030	0.5

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** No overlap anticipated.

***Proposal/Active Project Title:** Community Engagement for IoT4Ag Center - Year 5

***Status of Support:** Pending

Proposal/Award Number: EEC- 1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** Gainesville, FL

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.3
2024	0.9
2025	0.3

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** This sub-award would be a continuation of Seed funding secured from 3/2023-9/2023. Seed funding and continuation is to provide leadership for community engagement efforts, primarily with producers and technology end-users.

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Stofer, Kathryn in SciENcv on 2024-08-26 16:27:55

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Turner, Kevin

*POSITION TITLE: Professor

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** Materials Research science and Engineering Centers (MRSEC) UPENN

***Status of Support:** Current

Proposal/Award Number: N/A

***Source of Support:** NSF/Division of Materials Research

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2023

***Proposal/Active Project End Date: (MM/YYYY):** 08/2029

***Total Anticipated Proposal/Project Amount:** $27,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1
2025	0.1
2026	0.1
2027	0.1
2028	0.1
2029	0.5

***Overall Objectives:** The LRSM seeks to explore materials, function, and property relationships through two interdisciplinary research teams, and provide a robust education and outreach program to the broad community.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Investigating mechanisms of stretch-induced whitening in PET with increased recyclability

***Status of Support:** Current

Proposal/Award Number: 1060176-470795

***Source of Support:** CARNEGIE MELLON UNIVERSITY (PENNSYLVANIA DEPARTMENT OF COMMU

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 08/2023

***Proposal/Active Project End Date: (MM/YYYY):** 09/2024

***Total Anticipated Proposal/Project Amount:** $69,373

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.1

***Overall Objectives:** The objective of this proposal is to characterize the internal structure and mechanics of Penn Color's PET technology using fracture-based tests, electron microscopy, and modeling at UPenn. This will lead to an understanding of the critical properties that lead to whitening and measurements of the mechanical properties within the package walls. This will allow for optimization of current PET formulas and potentially the development of new materials that exploit the same effect.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** An integrated nano- and micro-indentation system for musculoskeletal tissue and biomaterials

***Status of Support:** Current

Proposal/Award Number: 1-S10-OD-032458-01A1

***Source of Support:** NIH

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2023

***Proposal/Active Project End Date: (MM/YYYY):** 03/2025

***Total Anticipated Proposal/Project Amount:** $691,040

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** EQUIPMENT GRANT

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** Nanocellulose infiltrated paper substrates for printed sensors and electronics

***Status of Support:** Current

Proposal/Award Number: 23-JV-11111122-020

***Source of Support:** DEPARTMENT OF AGRICULTURE FOREST SERVICE

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 04/2023

***Proposal/Active Project End Date: (MM/YYYY):** 05/2026

***Total Anticipated Proposal/Project Amount:** $399,920

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5
2026	0.5

***Overall Objectives:** Development of scalable processes for manufacturing distortion-free NCIP substrates that have smooth and non-porous surfaces for high-fidelity printing of electronics. Demonstration of screen-printed NCIP wireless moisture sensors for packaging applications.

***Statement of Potential Overlap:** No Overlap

***Proposal/Active Project Title:** PFI-RP: Compliant Manipulation of Small, Delicate, and Curved Objects Using Dynamically Tunable Dry Adhesion

***Status of Support:** Current

Proposal/Award Number: 32628-06220-S01

***Source of Support:** SYRACUSE UNIV (NATIONAL SCIENCE FOUNDATION)

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 05/2022

***Proposal/Active Project End Date: (MM/YYYY):** 03/2025

***Total Anticipated Proposal/Project Amount:** $268,750

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.25

***Overall Objectives:** This project aims to exploit tunable adhesion based on subsurface stiffness modulation for manipulating small components in pick-and-place manufacturing processes.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** Leveraging modeling-based bone formation for osteoporosis treatment

***Status of Support:** Current

Proposal/Award Number: 1-R01-AR-077598-01A1

***Source of Support:** NATIONAL INSTITUTE OF ARTHRITIS & MUSCULOSKELETAL & SKIN DIS

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 03/2021

***Proposal/Active Project End Date: (MM/YYYY):** 01/2026

***Total Anticipated Proposal/Project Amount:** $2,269,099

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.36
2026	0.36

***Overall Objectives:** This project is related to the the effects of osteoporosis treatment on the mechanical properties of bone. Turner's objective in this project is to assist in the nanomechanical characterization of bone via nanoindentation.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** NNCI: Establishment of a Nanotechnology User Node at the University of Pennsylvania

***Status of Support:** Current

Proposal/Award Number: ECCS-2025608

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $4,200,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	0.5
2025	0.5

***Overall Objectives:** This project supports a multi-user shared nanotechnology fabrication and characterization facility at U. Pennsylvania. This is a continuation of the previous NNCI support.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,080,462

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2024	1
2025	1

***Overall Objectives:** This project aims to develop internet of things technologies (IoT), such as sensors, robotics, communication methods, and data analytics for precision agriculture.

***Statement of Potential Overlap:** None

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1
2027	1
2028	1
2029	1
2030	1

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My groups work is to design, fabricate, and characterize materials and devices for optical and RF sensors and antennas.

***Statement of Potential Overlap:** None - THIS PROPOSAL

***Proposal/Active Project Title:**	DURIP: Planar Fabrication System for Research on Devices with Integrated Sensing, Actuation, and Control
***Status of Support:**	Pending
Proposal/Award Number:	N/A
***Source of Support:**	DEPARTMENT OF THE ARMY
***Primary Place of Performance:**	University of Pennsylvania
***Proposal/Active Project Start Date: (MM/YYYY):**	12/2024
***Proposal/Active Project End Date: (MM/YYYY):**	11/2025
***Total Anticipated Proposal/Project Amount:**	$322,452

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0,1

***Overall Objectives:** We propose to assemble a fabrication system for automated manufacturing of 2D and 2.5D structures. The new fabrication capabilities associated with this equipment will: (i) enable automated and repeatable evaluation of novel 2D fabrication methods for active, morphing, and programmable structures; and (ii) transform and expand our rapid prototyping capabilities in order to accelerate empirical studies of how to incorporate such structures into future robotic platforms.

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:**	Au-TiO2-Al2O3 nanocomposites for multi-analyte detection and plant health monitoring
***Status of Support:**	Pending
Proposal/Award Number:	N/A
***Source of Support:**	Goeppert LLC (NASA SBIR)
***Primary Place of Performance:**	University of Pennsylvania
***Proposal/Active Project Start Date: (MM/YYYY):**	08/2024
***Proposal/Active Project End Date: (MM/YYYY):**	02/2025
***Total Anticipated Proposal/Project Amount:**	$46,231

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.1

***Overall Objectives:** The objective is to explore the use of Au-TiO2-Al2O3 nanocomposites as sensors to detect plant health,

***Statement of Potential Overlap:** This project, led by Goeppert LLC, uses distinct materials/devices from any sensors in IoT4Ag. Thus, there is no overlap. However, the project is synergistic with IoT4Ag, given the application of plant health sensing,

***Proposal/Active Project Title:** Collaborative Research: Modulating Friction of Solid Contacts through Materials with Tunable Stiffness

***Status of Support:** Pending

Proposal/Award Number: N/A

***Source of Support:** NATIONAL SCIENCE FOUNDATION

***Primary Place of Performance:** University of Pennsylania

***Proposal/Active Project Start Date: (MM/YYYY):** 06/2024

***Proposal/Active Project End Date: (MM/YYYY):** 05/2027

***Total Anticipated Proposal/Project Amount:** $444,147

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	0.5
2026	0.5
2027	0.5

***Overall Objectives:** The overarching research objective of the proposed work is to investigate the mechanics of modulating the friction of solid contacts via stiffness tuning of one of the contacting bodies.

***Statement of Potential Overlap:** None

Certification:

I certify that the information provided is current, accurate, and complete. This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Turner, Kevin in SciENcv on 2024-08-22 16:40:55

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors.
Follow this format for each person.

*NAME: Weiner, Steven S

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0009-0004-3070-9034

*POSITION TITLE: Sr. Director for Innovation and Technology and Lecturer

*ORGANIZATION AND LOCATION: University of Pennsylvania, Philadelphia, Pennsylvania, United States

Proposals/Active Projects

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Current

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2020

***Proposal/Active Project End Date: (MM/YYYY):** 08/2025

***Total Anticipated Proposal/Project Amount:** $26,008,099

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2021	3
2022	3
2023	3
2024	3
2025	3

***Overall Objectives:** Industry Liaison Officer: co-leadership of Innovation Ecosystem functions and goals, focusing on industry and stakeholder engagement

***Statement of Potential Overlap:** No overlap

***Proposal/Active Project Title:** NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)

***Status of Support:** Pending

Proposal/Award Number: EEC-1941529

***Source of Support:** National Science Foundation

***Primary Place of Performance:** University of Pennsylvania

***Proposal/Active Project Start Date: (MM/YYYY):** 09/2025

***Proposal/Active Project End Date: (MM/YYYY):** 08/2030

***Total Anticipated Proposal/Project Amount:** $29,336,832

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	2.5
2027	2.5
2028	2.5
2029	1
2030	1

***Overall Objectives:** Industry Liaison Officer: co-leadership of Innovation Ecosystem functions and goals, focusing on industry and stakeholder engagement

***Statement of Potential Overlap:** No overlap

Certification:

I certify that the information provided is current, accurate, and complete, This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802.

Certified by Weiner, Steven in SciENcv on 2024-08-27 14:06:49

CURRENT AND PENDING (OTHER) SUPPORT INFORMATION

Provide the following information for the Senior/key personnel and other significant contributors. Follow this format for each person.

*NAME: Yeo, M, Lisa

PERSISTENT IDENTIFIER (PID) OF THE SENIOR/KEY PERSON: https://orcid.org/0000-0002-6648-3557

*POSITION TITLE: Assistant Professor

*ORGANIZATION AND LOCATION: University of California Merced, Merced, California, United States

Proposals/Active Projects

***Proposal/Active Project Title:**	NSF ENGINEERING RESEARCH CENTER FOR THE INTERNET OF THINGS FOR PRECISION AGRICULTURE (IoT4Ag)
***Status of Support:**	Current
Proposal/Award Number:	EEC-1941529
***Source of Support:**	NSF/Penn
***Primary Place of Performance:**	University of California, Merced
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2020
***Proposal/Active Project End Date: (MM/YYYY):**	08/2025
***Total Anticipated Proposal/Project Amount:**	$3,705,736

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2022	1
2023	1
2024	1
2025	1

***Overall Objectives:** The IoT4Ag ERC aims to create and translate to practice Internet of Things technologies and systems for precision agriculture. My group's work is to design and analyze an ag data value model and provide guidance for equitable distribution of value across the ag data supply chain. We will conduct case study interviews of data use and governance with industry partners, share economic model of data value in ag data supply chain, perform a critical analysis of benefit-risk in ag data supply chain, and identify policy implications for managing data value in ag data supply chain.

***Statement of Potential Overlap:** There is no overlap with any pending proposal in terms of research goals, Budget: My group is funded for one graduate student (GSR) and up to two undergraduate researchers, PI summer support according to the dedicated person months indicated, and an allocation for research dissemination costs (e.g. conference travel, open access publication fees). PI:

***Proposal/Active Project Title:**	NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	NSF/Penn
***Primary Place of Performance:**	University of California, Merced
***Proposal/Active Project Start Date: (MM/YYYY):**	09/2025
***Proposal/Active Project End Date: (MM/YYYY):**	08/2030
***Total Anticipated Proposal/Project Amount:**	$4,214,111

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2026	1.53
2027	1.5
2028	1.47
2029	1.01
2030	0.49

***Overall Objectives:** The goal of this center is to ensure food, energy, and water security by advancing technology to increase crop production while minimizing the use of energy and water resources and the impact of agricultural practices on the environment. To realize this mission, IoT4Ag is creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and train an educated and diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.

***Statement of Potential Overlap:** There is no overlap with current IoT4Ag NSF ERC grant which ends in 2025 as this is the extension for that grant. There is potential overlap with CIPHER proposal in that work that I do with IoT4Ag informs the curriculum and content of courses proposed under that project. However, it is more likely that the CIPHER & IoT4Ag activities are synergistic than overlapping. These projects have different scope, budget, and there is no overlap in time commitment.

***Proposal/Active Project Title:**	(CIPHER) Collaborative Initiative for Promoting Higher Education and Research in cybersecurity
***Status of Support:**	Pending
Proposal/Award Number:	
***Source of Support:**	DOE
***Primary Place of Performance:**	University of California Merced
***Proposal/Active Project Start Date: (MM/YYYY):**	01/2025
***Proposal/Active Project End Date: (MM/YYYY):**	12/2029
***Total Anticipated Proposal/Project Amount:**	$5,000,000

*** Person Months per budget period Devoted to the Proposal/Active Project:**

Year	Person Months
2025	1
2026	1
2027	1
2028	1
2029	1

***Overall Objectives:** The overall objective of this project consists of the following: (i) to enhance educational opportunities at MSIs in the field of Cybersecurity to produce a sustainable workforce for research and development at NNSA labs, (ii) to enhance educational opportunities and improve the capacity of the minority-serving institutions (MSIs) to recruit and prepare scientists for research careers in the STEM field, viz Cybersecurity, and (iii) to accelerate research in the area of Cybersecurity at MSIs and foster research and teaching collaboration among MSIs,

***Statement of Potential Overlap:** none

Certification:

I certify that the information provided is current, accurate, and complete, This includes but is not limited to current, pending, and other support (both foreign and domestic) as defined in 42 U.S.C. § 6605.

I also certify that, at the time of submission, I am not a party to a malign foreign talent recruitment program.

Misrepresentations and/or omissions may be subject to prosecution and liability pursuant to, but not limited to, 18 U.S.C. §§ 287, 1001, 1031 and 31 U.S.C. §§ 3729-3733 and 3802,

Certified by Yeo, M. Lisa in SciENcv on 2024-07-17 16:10:30

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APPENDIX XIII. NSF FORM 1030 BUDGET REQUEST

The renewal year budgets for each year plus the summary budget for the total support (NSF Budget Form 1030) for the four core partner institutions (University of Pennsylvania, Purdue University, University of Florida, and University of California – Merced), including the subaward to Arizona State University, start on the next page.

Year 1

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
AWARD NO.		

ORGANIZATION: The Trustees of the University of Pennsylvania

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cherie Kagan

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior — List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Cherie Kagan (PI)	1.50	-	-	47,534	$
2. Paulo Arratia (Co-PI)	0.27	-	-	6,091	
3. Kevin Turner (Sr. Personnel)	1.00	-	-	24,220	
4. Mark Allen (Sr. Personnel)	0.30	-	-	11,428	
5. Roy Olsson (Sr. Personnel)	0.50	-	-	9,528	
6. (5) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	26.83	-	-	296,836	
7. (10) TOTAL SENIOR PERSONNEL (1-6)	30.39	0.00	0.00	395,637	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (2) POSTDOCTORAL ASSOCIATES	24.00	-	-	132,600	
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.20	-	-	5,981	
3. (10) GRADUATE STUDENTS				418,000	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. (1) OTHER – Communication Assistant				5,200	
TOTAL SALARIES AND WAGES (A + B)				957,418	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				154,822	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,112,240	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				46,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 36,000					
2. TRAVEL 1,000					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS (5) TOTAL PARTICIPANT				37,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				254,267	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				3,232,270	
6. OTHER – GSTuition/Fees; Research/Work Dev/Diversity/Lead Admin Expenses; Annual Retreat				309,781	
TOTAL OTHER DIRECT COSTS				3,796,318	
H. TOTAL DIRECT COSTS (A THROUGH G)				4,991,558	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
62.5% ← IDC %					
1,613,507 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				1,008,442	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				6,000,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				6,000,000	$

M. COST SHARING: PROPOSED LEVEL $1,155,323 AGREED LEVEL IF DIFFERENT: $

PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY
Cherie Kagan	8/9/2024	INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date / Date of Rate Sheet / Initials-ORG
William Burns	8/9/2024	

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 2

SUMMARY PROPOSAL BUDGET				FOR NSF USE ONLY		
ORGANIZATION The Trustees of the University of Pennsylvania				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cherie Kagan				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. Cherie Kagan (PI)	1.50	-	-	48,960	$	
2. Paulo Arratia (Co-PI)	0.26	-	-	6,159		
3. Kevin Turner (Sr. Personnel)	1.00	-	-	24,947		
4. Mark Allen (Sr. Personnel)	0.29	-	-	11,543		
5. Roy Olsson (Sr. Personnel)	0.48	-	-	9,587		
6. (5) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	26.83	-	-	305,626		
7. (10) TOTAL SENIOR PERSONNEL (1-6)	30.37	0.00	0.00	406,822		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (2) POSTDOCTORAL ASSOCIATES	24.00	-	-	136,578		
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.20	-	-	6,161		
3. (10) GRADUATE STUDENTS				451,440		
4. ( ) UNDERGRADUATE STUDENTS				-		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. (1) OTHER – Communication Assistant				5,356		
TOTAL SALARIES AND WAGES (A + B)				1,006,357		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				159,251		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,165,608		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				51,000		
2. FOREIGN				-		
F. PARTICIPANT SUPPORT						
1. STIPENDS $ 36,000						
2. TRAVEL 1,000						
3. SUBSISTENCE -						
4. OTHER -						
TOTAL NUMBER OF PARTICIPANTS (5) TOTAL PARTICIPANT				37,000		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				229,223		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				3,232,270		
6. OTHER – GSTuition/Fees; Research/Work Dev/Diversity/Lead Admin Expenses; Annual Retreat				318,130		
TOTAL OTHER DIRECT COSTS				3,779,623		
H. TOTAL DIRECT COSTS (A THROUGH G)				5,033,231		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)						
62.5% ← IDC %						
1,546,831 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				966,769		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				6,000,000		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				6,000,000	$	
M. COST SHARING: PROPOSED LEVEL $1,155,317	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE*	DATE			FOR NSF USE ONLY		
Cherie Kagan	8/9/2024			INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE*	DATE			Date	Date of Rate Sheet	Initials-ORG
William Burns	8/9/2024					

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 3

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: The Trustees of the University of Pennsylvania	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cherie Kagan	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Cherie Kagan (PI)	1.50	-	-	50,428	$
2. Paulo Arratia (Co-PI)	0.26	-	-	6,230	
3. Kevin Turner (Sr. Personnel)	1.00	-	-	25,895	
4. Mark Allen (Sr. Personnel)	0.29	-	-	11,661	
5. Roy Olsson (Sr. Personnel)	0.47	-	-	9,647	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	26.60	-	-	307,798	
7. (10) TOTAL SENIOR PERSONNEL (1-6)	30.12	0.00	0.00	411,459	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (2) POSTDOCTORAL ASSOCIATES	24.00	-	-	140,676	
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.20	-	-	6,346	
3. (10) GRADUATE STUDENTS				464,980	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. (1) OTHER – Communication Assistant				5,517	
TOTAL SALARIES AND WAGES (A + B)				1,028,978	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				161,648	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,190,626	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				46,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 36,000					
2. TRAVEL 1,000					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS (5) TOTAL PARTICIPANT				37,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				208,357	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				3,232,270	
6. OTHER – GSTuition/Fees; Research/Work Dev/Diversity/Lead Admin Expenses; Annual Retreat				322,320	
TOTAL OTHER DIRECT COSTS				3,762,947	
H. TOTAL DIRECT COSTS (A THROUGH G)				5,036,573	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
62.5% ← IDC %					
1,541,483 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				963,427	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				6,000,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				6,000,000	$

M. COST SHARING: PROPOSED LEVEL $1,155,336	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* Cherie Kagan	DATE 8/9/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* William Burns	DATE 8/9/2024	Date / Date of Rate Sheet / Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 4

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
AWARD NO.		

ORGANIZATION: The Trustees of the University of Pennsylvania

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cherie Kagan

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Cherie Kagan (PI)	1.50	-	-	51,941	$
2. Paulo Arratia (Co-PI)	0.15	-	-	3,752	
3. Kevin Turner (Sr. Personnel)	1.00	-	-	26,466	
4. Mark Allen (Sr. Personnel)	0.15	-	-	6,267	
5. Roy Olsson (Sr. Personnel)	0.30	-	-	6,307	
6. (3) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	19.00	-	-	221,889	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	22.10	0.00	0.00	316,622	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	6.00	-	-	36,224	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (7) GRADUATE STUDENTS				335,251	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. (1) OTHER – Communication Assistant				5,882	
TOTAL SALARIES AND WAGES (A + B)				693,779	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				107,854	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				801,633	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				17,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 16,000					
2. TRAVEL 1,000					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT				17,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				138,101	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				2,155,037	
6. OTHER – GSTuition/Fees; Research/Work Dev/Diversity/Lead Admin Expenses; Annual Retreat				231,395	
TOTAL OTHER DIRECT COSTS				2,524,533	
H. TOTAL DIRECT COSTS (A THROUGH G)				3,360,166	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
62.5% ← IDC %					
1,023,734 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				639,834	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				4,000,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				4,000,000	$

M. COST SHARING: PROPOSED LEVEL $770,215 AGREED LEVEL IF DIFFERENT: $

PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY
Cherie Kagan	8/9/2024	INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date / Date of Rate Sheet / Initials-ORG
William Burns	8/9/2024	

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 5

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: The Trustees of the University of Pennsylvania	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cherie Kagan	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Cherie Kagan (PI)	1.50	-	-	53,499	$
2. Paulo Arratia (Co-PI)	0.10	-	-	2,576	
3. Kevin Turner (Sr. Personnel)	1.00	-	-	27,260	
4. Mark Allen (Sr. Personnel)	0.10	-	-	4,304	
5. Roy Olsson (Sr. Personnel)	0.15	-	-	3,248	
6. (3) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	13.00	-	-	158,077	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	15.85	0.00	0.00	248,964	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (5) GRADUATE STUDENTS				197,320	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. (1) OTHER – Communication Assistant				5,853	
TOTAL SALARIES AND WAGES (A + B)				452,137	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				78,950	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				531,087	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				6,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 16,000					
2. TRAVEL 1,000					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT				17,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				100,347	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				1,401,536	
6. OTHER – GSTuition/Fees; Research/Work Dev/Diversity/Lead Admin Expenses; Annual Retreat				127,196	
TOTAL OTHER DIRECT COSTS				1,629,079	
H. TOTAL DIRECT COSTS (A THROUGH G)				2,183,166	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
62.5% ← IDC %					
666,934 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				416,834	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				2,600,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				2,600,000	$

M. COST SHARING: PROPOSED LEVEL $500,641	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* Cherie Kagan	DATE 8/9/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* William Burns	DATE 8/9/2024	Date / Date of Rate Sheet / Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Cumulative

SUMMARY PROPOSAL BUDGET				FOR NSF USE ONLY		
ORGANIZATION The Trustees of the University of Pennsylvania				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Cherie Kagan				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. Cherie Kagan (PI)	7.50	-	-	252,362	$	
2. Paulo Arratia (Co-PI)	1.03	-	-	24,808		
3. Kevin Turner (Sr. Personnel)	5.00	-	-	128,588		
4. Mark Allen (Sr. Personnel)	1.13	-	-	45,203		
5. Roy Olsson (Sr. Personnel)	1.90	-	-	38,317		
6. (10) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	112.26	-	-	1,290,226		
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	128.82	0.00	0.00	1,779,504		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (7) POSTDOCTORAL ASSOCIATES	78.00	-	-	446,078		
2. (2) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.60	-	-	18,488		
3. ( ) GRADUATE STUDENTS				1,866,991		
4. ( ) UNDERGRADUATE STUDENTS				-		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				27,608		
TOTAL SALARIES AND WAGES (A + B)				4,138,669		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				662,525		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				4,801,194		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				166,000		
2. FOREIGN				-		
F. PARTICIPANT SUPPORT 1. STIPENDS $ 140,000 2. TRAVEL 5,000 3. SUBSISTENCE - 4. OTHER -						
TOTAL NUMBER OF PARTICIPANTS (16) TOTAL PARTICIPANT				145,000		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				930,295		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				13,253,383		
6. OTHER – Describe				1,308,822		
TOTAL OTHER DIRECT COSTS				15,492,500		
H. TOTAL DIRECT COSTS (A THROUGH G)				20,604,694		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 62.5% ← IDC % 6,392,489 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				3,995,306		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				24,600,000		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				24,600,000	$	
M. COST SHARING: PROPOSED LEVEL $4,736,832	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* Cherie Kagan	DATE 8/9/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* William Burns	DATE 8/9/2024			Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

BUDGET JUSTIFICATION
University of Pennsylvania

Senior Personnel:

Cherie Kagan, Professor, PI (1.5 months annual effort). As the Center Director, the PI will direct and oversee all aspects of the Center, including supervising the Administrative Director and the Director of Education and Inclusivity. Dr. Kagan will also conduct research, participate in education and inclusion programming, engage in innovation and commercialization, and supervise the students and postdoctoral fellows associated with her research.

Paulo Arratia, Professor, Co-PI (0.27-month Y6, 0.26-month Y7, 0.26-month Y8, 0.15-month Y9, and 0.10-month Y10 annual effort). Dr. Arratia will co-lead the Diversity & Culture of Inclusion activities of the Center, and will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Mark Allen, Professor, Sr. Personnel (0.30-month Y6, 0.29-month Y7, 0.29-month Y8, 0.15-month Y9, and 0.10-month Y10 annual effort) Prof. Allen will co-lead the Thrust 2 research of the Center, and will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Sue Ann Bidstrup Allen, Professor, Sr. Personnel (0.23-month Y6 and 0.23-month Y7 annual effort) Prof. Bidstrup-Allen will co-lead the Engineering Workforce Development activities of the Center and will conduct her own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise her students and/or postdoctoral fellows.

Pratik Chaudhari, Assistant Professor, Sr. Personnel (0.10-month Y6, 0.10-month Y7, and 0.10-month Y8 annual effort) Prof. Chaudhari will serve on the Convergence Research team and will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Roy (Troy) Olsson, Professor, Sr. Personnel (0.50-month Y6, 0.48-month Y7, 0.47-month Y8, 0.30-month Y9, and 0.15-month Y10 annual effort) Prof. Olsson will co-lead the Thrust 1 research of the Center, and will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Kevin Turner, Professor, Sr. Personnel (1-month annual effort) Prof. Turner will co-lead the Convergent Research of the Center, and will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Bob Brier, Administrative Director, Sr. Personnel (12-months Y6, 12-months Y7, 12-months Y8, 9-months Y9, and 6-months Y10 annual effort) Mr. Brier will direct and oversee the administrative

activities of the Center, including the oversight of the NSF Site Visit, the annual retreat, and the annual report submission.

Kristin Field, EWD/DCI Director, Sr. Personnel (12-month Y6, 12-months Y7, 12-months Y8, 9-months Y9, and 6-months Y10 annual effort) Dr. Field will co-lead the Engineering Workforce Development and the Diversity & Culture of Inclusion activities of the Center.

Steven Weiner, JD, IoT4Ag ILO, Sr. Personnel (2.5-months Y6, 2.5-months Y7, 2.5-months Y8, 1-month Y9, and 1-month Y10 annual effort)) Mr. Weiner will co-lead the Innovation Ecosystem activities of the Center.

Other Personnel:

Vijay Kumar, Professor, Faculty Researcher (0.10-month annual effort Y6-Y8) Prof. Kumar will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Alejandro Ribeiro, Professor, Faculty Researcher (0.10-month annual effort Y6-Y8) Prof. Ribeiro will conduct his own research within the Center, participate in education and inclusion programming, engage in innovation and commercialization, and supervise his students and/or postdoctoral fellows.

Postdoctoral Researcher, TBD (2 Postdocs 24-months annual effort Y6-Y8; and 1 Postdoc 6-months annual effort YR9) Postdocs will be recruited with expertise in the Center's research, specific to one of the Center's faculty members research projects.

Graduate Research Assistant, TBD (10 GRA 120-months annual effort Y6-Y8; 7 GRA 84-months annual effort YR9; and 5 GRA 48-months annual effort YR10) A Doctoral candidate graduate student will be with expertise in the Center's research, specific to one of the Center's faculty members research projects.

Sherry Xu, Communication Assistant (1.5-months annual effort) Ms. Xu will assist the Center with graphic design, website updates and maintenance, social media posting, and marketing material development.

The University of Pennsylvania reports the effort of the faculty, postdocs and graduate students as a percentage of monthly effort. The University does not report or record hours or hourly rates for these positions. The effort detailed in this budget is based on an historical estimate of projects of this nature by the PI's. Funded effort is requested in monthly increments. Therefore 1.0 equals 1 month, 0.5 equals 1/2 month and so on. For purposes of estimating, partial months can be calculated based on an average of 22 working days per month. Hourly rates for other categories are based on a 40-hour week.

Employee Benefits:

The employee benefits rates are proposed at **31.5%** for faculty and full-time staff, 21% for postdoctoral researchers. These rates are based on our federal rate agreement signed May 27, 2024, and are subject to

change. In lieu of employee benefits, graduate students receive tuition and associated fees (including health insurance) which are treated as a direct expense to this project.

Travel:

Domestic Travel ($46,000 Y6, $51,000 Y7, $46,000 Y8, $17,000 Y9, and $6,000 Y10):

Funds are budgeted for travel for the following: SAB, EWD / DCI and ASAB Advisory Board Travel to the IoT4Ag Annual Retreat and NSF Site Visit, and IoT4Ag member travel to the Student Bootcamp, Annual Retreat, NSF Site Visit, Biennial ERC meetings and participation in education and outreach events. The purposes for the travel include dissemination of results and programs and direct interaction with peers in the field and colleagues in the Center. Included in the budget estimate is airfare, registration, hotel, and per diem. Rates are based on past experience and do not exceed published GSA rates at time of proposal.

Participant Stipends – REU ($16,000/year – 2 Participants):

Funds are budgeted for the Research Experiences for Undergraduates (REU) students to participate in IoT4Ag training and research during the summer months.

Participant Travel – REU ($1,000/year – 2 Participants):

Travel expenses are budgeted for REU students between their home and the Penn campus to participate in the summer IoT4Ag program

Participant Stipends – RET ($20,000/year Y6-Y8 – 3 Participants):

Funds are budgeted for the Research Experiences for Teachers (RET) participants to participate in IoT4Ag training and research during the summer months.

Materials and Supplies ($254,267 Y6, $229,223 Y7, $208,357 Y8, $138,101 Y9, and $100,347 Y10):

Funds are requested for materials, set-up and testing of the various experiments, and other expenses related to the specific tasks detailed in the text of the proposal. This includes purchase of instrumentation, and other laboratory materials including glassware, chemicals, optics, electronic components etc. as well as computers, computer supplies, peripheral devices, and software to meet the project goals.

Research: Seminar Series ($12,000 Y6, $12,000 Y7, $12,000 Y8, $9,000 Y9, and $6,000 Y10):

Funds are budgeted for the Seminar Series to host external speakers at one of the four partner institution campuses, broadcasted across the Center to build knowledge of the work of our peers.

Research: Scientific Advisory Board Honorarium ($3,000/year Y6-Y9):

Funds are budgeted to support the Scientific Advisory Board members for their service to the Center in advisory board meetings, as project liaisons, in providing feedback on research projects, and participation in the NSF Site Visit and the IoT4Ag Annual Retreat.

Engineering Workforce Development: University Education – Boot Camp ($7,000 Y6, $7,000 Y7, $7,000 Y8, and $6,000 Y9):

Funds are budgeted to support the IoT4Ag student and postdoctoral fellow bootcamp prior to the annual retreat for team and community building and networking activities.

Engineering Workforce Development: EXCITE – Tech Meets Ag – K-12 Outreach and Education Partnerships ($4,500 YR6–YR7, $2,000 YR8–YR10):

Funds are budgeted to support K-12 education and outreach partnerships with schools, camps and museums.

Engineering Workforce Development: Intra-Exchange (ITEX) ($10,000 Y6, $10,000 Y7, $10,000 Y8, $7,500 Y9, and $5,000 Y10):
Funds are budgeted to support travel-related expenses for graduate students and postdoctoral fellows to collaborate on research projects at another partner institution campus of the Center.

Engineering Workforce Development (EWD) and Diversity & Culture of Inclusion (DCI): Advisory Board Honorarium ($6,000 Y6, $6,000 Y7, $4,000 Y8, and $3,000 Y9):
Funds are budgeted to support the Engineering Workforce and Diversity & Culture of Inclusion Advisory Board members for their service to the Center in advisory board meetings, feedback on the Center's EWD and DCI activities and programs, and participation in the NSF Site Visit and the IoT4Ag Annual Retreat.

Diversity: Climate - Mentoring, Tri-Annual Check-Ins and Student & Fellow events ($1,000 Y6, $1,000 Y7, $1,000 Y8, $500 Y9, and $500 Y10):
Funds are budgeted to support the student and postdoctoral event expenses for team and community building at the Penn campus and across all the Center campuses.

Diversity: Pathway to PhD Program ($11,500 Y6, $11,500 Y7, $11,500 Y8, $4,000 Y9, and $2,000 Y10):
Funds are budgeted to support the annual Pathway to PhD program, such as mentorship stipends, communication about the program, and development of scalable and sustainable programming (e.g., production of video content).

Diversity: Registration Fees for Outreach (e.g., SCANAS, NSBE, MANRRS) ($3,000 Y6, $3,000 Y7, $3,000 Y8, $1,000 Y9, and $1,000 Y10):
Funds are budgeted to support the registration fees for Diversity & Culture of Inclusion conferences and events.

Diversity: MSI & HBCU Partnership Scholars Network ($10,000/year Y6-Y8):
Funds are budgeted to support the faculty and their undergraduate students from Minority Serving Institutions (MSI) and Historically Black Colleges and Universities (HBCU) for their participation during the summer at IoT4Ag and the Penn campus.

Lead Admin: Communication ($13,000/year):
Funds are budgeted for communication platforms, such as Slack, Airtable, website maintenance, and database support for the Center.

Annual Retreat ($20,000 Y6, $20,000 Y7, $20,000 Y8, and $18,000 Y9):
Funds are budgeted to support the conference-related expenses associated with the Center's annual retreat that is held each year and rotates between the partner institutions of the Center.

Consortium/Contractual/Subcontract:
A subcontract will be established with **Arizona State University (ASU)**, a domestic institution of higher education. ASU leads the evaluation and assessment activities of the Center, across all four partner institution campuses.

The subaward PI will be Prof. Ayesha Boyce.
The estimated total costs per year for the 5-year project are as follows:

Year 01	$57,000
Year 02	$57,000
Year 03	$57,000
Year 04	$38,190
Year 05	$25,587
Total	**$234,777**

Consortium/Contractual/Subcontract:
A subcontract will be established with **Purdue University**, a domestic institution of higher education. Purdue University is one of the partner institutions of the Center and leads the activities of the following ERC foundational components at its campus: Research, Engineering Workforce Development, Diversity & Culture of Inclusion and Administration.

The subaward PI will be Prof. David Cappelleri.
The estimated total costs per year for the 5-year project are as follows:

Year 01	$1,124,690
Year 02	$1,124,690
Year 03	$1,124,690
Year 04	$749,793
Year 05	$487,366
Total	**$4,611,229**

Consortium/Contractual/Subcontract:
A subcontract will be established with the **University of Florida**, a domestic institution of higher education. University of Florida is one of the partner institutions of the Center and leads the activities of the following ERC foundational components at its campus: Research, Engineering Workforce Development, Diversity & Culture of Inclusion, Innovation Ecosystem and Administration.

The subaward PI will be Prof. David Arnold.
The estimated total costs per year for the 5-year project are as follows:

Year 01	$1,156,813
Year 02	$1,156,813
Year 03	$1,156,813
Year 04	$771,209
Year 05	$501,286
Total	**$4,742,934**

Consortium/Contractual/Subcontract:
A subcontract will be established with the **University of California Merced**, a domestic institution of higher education. University of California Merced is one of the partner institutions of the Center and leads the activities of the following ERC foundational components at its campus: Research, Engineering Workforce Development, Diversity & Culture of Inclusion and Administration.

The subaward PI will be Prof. Stefano Carpin.
The estimated total costs per year for the 5-year project are as follows:

Year 01	$893,767
Year 02	$893,767
Year 03	$893,767
Year 04	$595,845
Year 05	$387,298
Total	**$3,664,444**

Other Direct Costs **- Graduate Student Tuition and Fees ($208,781 Y6, $217,130 Y7, $225,820 Y8, $164,395 Y9, and $97,696 Y10):**

Tuition is included for the graduate research assistant(s) for the equivalent of 3 courses per term in the academic year for each student. As explained in the salary & benefits section, tuition and fees are provided to graduate research assistants in lieu of employee benefits. Rates are increased annually by 4% based on past experience.

Indirect Costs (F&A):

Indirect costs are budgeted at **62.5%** per agreement signed May 27, 2024. Indirect costs are applied to a modified total direct cost base. The base is the sum of total direct costs, less the cost of equipment, tuition and that portion of any subcontract that exceeds $25,000.

Cost Share:

We propose cost sharing of **$2,316,279** which includes Penn's portion of faculty salary, graduate student effort, associated employee benefits, and a portion of graduate tuition. Cost-share will be funded from non-federal, unrestricted funds available to the school.

- Cherie Kagan: 5-months annual effort (Y1-Y5) salary and associated employee benefits = $1,106,184
- Graduate Student: 12-months annual effort (Y1-Y4) = $181,335
- Portion of Graduate Tuition = $543,413
- Indirect Costs = $485,347

Cost-Share by Institution:	
University of Pennsylvania	$2,316,279
Purdue University	$922,298
University of Florida	$948,588
University of California	$549,667
Total Cost-Share	**$4,736,832**

Year 1

SUMMARY PROPOSAL BUDGET						FOR NSF USE ONLY		
ORGANIZATION Purdue Unviversity						PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Cappelleri						AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)		NSF-Funded Person-months			Funds Requested By Proposer		Funds Granted by NSF (If Different)	
		CAL	ACAD	SUMR				
1. David Cappelleri		-		1.00	26,199	$		
2. Melba Crawford		-		1.00	31,997			
3. Dennis Buckmaster		-		1.00	23,796			
4. Daniel Quinn		-		1.00	13,930			
5. James Krogmeier		-		1.00	33,073			
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION		-		2.00	46,276			
7. (7) TOTAL SENIOR PERSONNEL (1-6)		0.00	0.00	7.00	175,271			
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)								
1. ( ) POSTDOCTORAL ASSOCIATES		-	-	-	-			
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)		-	-	-	-			
3. (5) GRADUATE STUDENTS					166,427			
4. ( ) UNDERGRADUATE STUDENTS					-			
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					-			
6. ( ) OTHER – Describe					-			
TOTAL SALARIES AND WAGES (A + B)					341,698			
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					59,974			
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)					401,672			
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)								
TOTAL EQUIPMENT					-			
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)					40,000			
2. FOREIGN					30,000			
F. PARTICIPANT SUPPORT								
1. STIPENDS	$							
2. TRAVEL	-							
3. SUBSISTENCE	-							
4. OTHER	16,000							
TOTAL NUMBER OF PARTICIPANTS (2)	TOTAL PARTICIPANT				16,000			
G. OTHER DIRECT COSTS								
1. MATERIALS AND SUPPLIES					109,436			
2. PUBLICATION/DOCUMENTATION/DISSEMINATION					10,000			
3. CONSULTANT SERVICES					-			
4. COMPUTER SERVICES					-			
5. SUBAWARDS					-			
6. OTHER – Graduate fee remissions, Workshops – DCI and Workshops – WFD					134,481			
TOTAL OTHER DIRECT COSTS					253,917			
H. TOTAL DIRECT COSTS (A THROUGH G)					741,589			
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)								
				57.0%	← IDC %			
				672,107	← IDC Base			
TOTAL INDIRECT COSTS (F&A)					383,101			
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)					1,124,690			
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)					-			
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)					1,124,690	$		
M. COST SHARING: PROPOSED LEVEL $224949		AGREED LEVEL IF DIFFERENT: $						
PI/PD TYPED NAME AND SIGNATURE*		DATE			FOR NSF USE ONLY			
David Cappelleri David J. Cappelleri		08/09/2024			INDIRECT COST RATE VERIFICATION			
ORG. REP. TYPED NAME & SIGNATURE*		DATE			Date	Date of Rate Sheet	Initials-ORG	
Melissa Martin Melissa Martin		08/09/2024						

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 2

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: Purdue Unviversity	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Cappelleri	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. David Cappelleri	-		1.00	27,247	$
2. Melba Crawford	-		1.00	33,277	
3. Dennis Buckmaster	-		1.00	24,748	
4. Daniel Quinn	-		1.00	14,488	
5. James Krogmeier	-		1.00	34,396	
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	-		2.00	48,127	
7. (7) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	7.00	182,283	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (5) GRADUATE STUDENTS				177,142	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				359,425	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				62,695	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				422,120	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				40,000	
2. FOREIGN				30,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ -					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER 16,000					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT				16,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				93,100	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				10,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Graduate fee remissions, Workshops – DCI and Workshops – WFD				130,874	
TOTAL OTHER DIRECT COSTS				233,974	
H. TOTAL DIRECT COSTS (A THROUGH G)				742,094	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
57.0% ← IDC %					
671,221 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				382,596	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,124,690	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				1,124,690	$

M. COST SHARING: PROPOSED LEVEL $224943	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* David Cappelleri (David J. Cappelleri)	DATE 08/09/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Melissa Martin (Melissa Martin)	DATE 08/09/2024	Date / Date of Rate Sheet / Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 3

SUMMARY PROPOSAL BUDGET					FOR NSF USE ONLY	
ORGANIZATION Purdue Unviversity					PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Cappelleri					AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months			Funds Requested By Proposer	Funds Granted by NSF (If Different)	
	CAL	ACAD	SUMR			
1. David Cappelleri	-		1.00	28,336	$	
2. Melba Crawford	-		1.00	34,608		
3. Dennis Buckmaster	-		1.00	25,738		
4. Daniel Quinn	-		1.00	15,067		
5. James Krogmeier	-		1.00	35,771		
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-		2.00	50,052		
7. (7) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	7.00	189,572		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-		
3. (4) GRADUATE STUDENTS				150,740		
4. ( ) UNDERGRADUATE STUDENTS				-		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				-		
TOTAL SALARIES AND WAGES (A + B)				340,312		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				62,535		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				402,847		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				40,000		
2. FOREIGN				30,000		
F. PARTICIPANT SUPPORT 1. STIPENDS $ - 2. TRAVEL - 3. SUBSISTENCE - 4. OTHER 16,000						
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT				16,000		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				114,172		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				10,000		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				-		
6. OTHER – Graduate fee remissions , Workshops – DCI and Workshops – WFD				125,769		
TOTAL OTHER DIRECT COSTS				249,941		
H. TOTAL DIRECT COSTS (A THROUGH G)				738,788		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 57.0% ← IDC % 677,021 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				385,902		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,124,690		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				1,124,690	$	
M. COST SHARING: PROPOSED LEVEL $224962	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* David Cappelleri David J. Cappelleri	DATE 08/09/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Melissa Martin Melissa Martin	DATE 08/09/2024			Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 4

SUMMARY PROPOSAL BUDGET					
ORGANIZATION Purdue Unviversity				FOR NSF USE ONLY PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Cappelleri				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. David Cappelleri	-		0.75	22,102	$
2. Melba Crawford	-		0.75	26,994	
3. Dennis Buckmaster	-		0.75	20,075	
4. Daniel Quinn	-		0.75	11,753	
5. James Krogmeier	-		0.75	27,902	
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	-		1.50	39,040	
7. (7) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	5.25	147,866	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (4) GRADUATE STUDENTS				161,388	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				309,254	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				52,270	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				361,524	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				28,000	
2. FOREIGN				20,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ -					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER 16,000					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT				16,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				14,848	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Graduate fee remissions, Workshops – DCI and Workshops – WFD				61,258	
TOTAL OTHER DIRECT COSTS				76,106	
H. TOTAL DIRECT COSTS (A THROUGH G)				501,630	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
57.0% ← IDC %					
435,373 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				248,163	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				749,793	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				749,793	$
M. COST SHARING: PROPOSED LEVEL $149965	AGREED LEVEL IF DIFFERENT: $				
PI/PD TYPED NAME AND SIGNATURE* David Cappelleri (David J. Cappelleri)	DATE 08/09/2024			FOR NSF USE ONLY	
				INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE* Melissa Martin (Melissa Martin)	DATE 08/09/2024			Date	Date of Rate Sheet / Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 5

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: Purdue Unviversity	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Cappelleri	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. David Cappelleri	-		0.50	15,324	$
2. Melba Crawford	-		0.50	18,716	
3. Dennis Buckmaster	-		0.50	13,919	
4. Daniel Quinn	-		0.50	8,148	
5. James Krogmeier	-		0.50	19,345	
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-		1.00	27,069	
7. (7) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	3.50	102,521	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (3) GRADUATE STUDENTS				111,436	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				213,957	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				36,203	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				250,160	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				10,000	
2. FOREIGN				10,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ -					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER 16,000					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT				16,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,096	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Graduate fee remissions, Workshops – DCI and Workshops – WFD				36,572	
TOTAL OTHER DIRECT COSTS				41,668	
H. TOTAL DIRECT COSTS (A THROUGH G)				327,828	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
			57.0%	← IDC %	
			279,892	← IDC Base	
TOTAL INDIRECT COSTS (F&A)				159,538	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				487,366	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				487,366	$

M. COST SHARING: PROPOSED LEVEL $97478	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE* David Cappelleri (David J. Cappelleri)	DATE 08/09/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Melissa Martin (Melissa Martin)	DATE 08/09/2024	Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Cumulative

SUMMARY PROPOSAL BUDGET				FOR NSF USE ONLY		
ORGANIZATION Purdue Unviversity				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Cappelleri				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. David Cappelleri	-	-	4.25	119,208	$	
2. Melba Crawford	-	-	4.25	145,592		
3. Dennis Buckmaster	-	-	4.25	108,276		
4. Daniel Quinn	-	-	4.25	63,386		
5. James Krogmeier	-	-	4.25	150,487		
6. (2) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	-	-	8.50	210,564		
7. (7) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	29.75	797,513		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-		
3. ( ) GRADUATE STUDENTS				767,133		
4. ( ) UNDERGRADUATE STUDENTS				-		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				-		
TOTAL SALARIES AND WAGES (A + B)				1,564,648		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				273,677		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,838,323		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				158,000		
2. FOREIGN				120,000		
F. PARTICIPANT SUPPORT						
1. STIPENDS $ -						
2. TRAVEL -						
3. SUBSISTENCE -						
4. OTHER 152,000						
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				80,000		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				336,652		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				30,000		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				-		
6. OTHER – Graduate fee remissions, Workshops – DCI and Workshops – WFD				488,954		
TOTAL OTHER DIRECT COSTS				855,606		
H. TOTAL DIRECT COSTS (A THROUGH G)				3,051,929		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)						
57.0% ← IDC %						
2,735,614 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				1,559,300		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				4,611,229		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				4,611,229	$	
M. COST SHARING: PROPOSED LEVEL $922298	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* David J. Cappelleri David Cappelleri	DATE 08/09/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Melissa Martin Melissa Martin	DATE 08/09/2024			Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

BUDGET JUSTIFICATION

In accordance with 2 CFR 200, Uniform Administrative Requirements, Cost Principles, And Audit Requirements for Federal Awards, Purdue University tracks and reports its professional personnel on a percent of effort and not on an hourly basis. Salaries are adjusted by standard University inflation rates each fiscal year (July 1) at 4%. Purdue University defines the term "year" as the university fiscal year (July-June) for purposes of the NSF Limitation on salary compensation for senior personnel.

A. Senior Personnel

Dr. David Cappelleri, PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Cappelleri will be the Purdue site leader for the proposed ERC and will work on Thrust 1 on Agricultural sensor systems.

Dr. Dennis Buckmaster, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Buckmaster will be the co-lead of Thrust 2 on Agricultural response systems.

Dr. Melba Crawford, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Crawford will be working on research related to Thrust 1 on Agricultural sensor systems and Thrust 2 on Agricultural response systems..

Dr. James Krogmeier, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Krogmeier will be working on research tasks as part of Thrust 3 on Communication and energy systems.

Dr. David Love, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Love will be the co-lead for Thrust 3 on Communication and energy systems.

Dr. Daniel Quinn, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Quinn will be performing research tasks as part of Thrust 1 on Agricultural sensing systems.

Dr. Yaguang Zhang, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Zhang will be performing research tasks as part of Thrust 2 on Agricultural response systems.

B. Other Personnel

TBA graduate students are requested each year, 5 for 29 months year 1-2; 4 for 24 months year 3; 5 for 25 months year 4; 3 for 16 months year 5. These graduate students will work with PIs Cappelleri, Crawford, Buckmaster, and Quinn on their respective research task in the thrusts listed above.

C. Fringe Benefits

Fringe benefits are budgeted in accordance with university policy as follows:

Faculty	26.65%
Grad Student	7.97%

D. Equipment

None

E. Travel

A total of $120,000 is budgeted for domestic travel for annual meetings. A total of $38,000 is budgeted for student travel to ERC sites. $120,000 foreign travel to conferences such as IEEE International

Conference on Robotics and Automation (ICRA), IEEE International Conference on Intelligent Robots and Systems (IROS), IEEE Global Communications (Globecom) Conference, Phenome Conference, IEEE Conference on Computer Vision and Pattern Recognition (CVPR), the annual meetings of the North American Plant Phenotyping Network (NAPPN), Crop Science Society of, and Nitrogen Use Efficiency Workshop.

F. Participant Support
$16,000 is budgeted for REU student support.

G. Other Direct Costs
1. Materials and supplies
General supplies are budgeted at $90,436 yr1, $74,100 yr2, $95,172 yr3, $14,848 yr4, $5,096 yr5 for costs associated with the following:

- Fabrication and testing of custom aerial and ground drone platforms
- Cameras, LiDARs, depth cameras, thermal cameras
- Embedded computers, microcontrollers, miscellaneous electronics and hardware components
- 3D printing filaments, machining services, rapid prototyping services, printed circuit boards
- High precision GPS and IMU sensors

Funds are budgeted to cover costs to host two seminars each year of the project. $5000 per year 1-3.

ACRE Transportation costs are requested each year for Purdue students traveling from campus to ACRE for research activities. $2000 per years 1-3.

ICSC user and rental fees are requested each year to support facility access and rental of required farming equipment for use on the plots at ACRE. $4000 per years 1-3.

Drone pilot fees are budgeted each year for hiring certified drone pilots for test flights at ACRE. $5000 per years 1-3.

DataDepot fees are requested each year for storing experimental sensing data. $1000 per years 1-3.

Funds for cellular data plans are requested each year to support wireless communications between sensors, drones, and base stations. $2000 per years 1-3.

2. Publication
Publication costs are requested for publishing fees associated with relevant journals to disseminate the research results from the ERC. $10,000 per years 1-3.

6. Workshop expenses
DCI Workshops; $11,000 yr1-2, $10,000 yr3, $3000 yr4, $2318 yr5
WFD Workshops; $70,000 yr1, $65,000 yr2, $70,000 yr3, $8,000 yr4, $2318 yr5
These workshops include the following:
Workshops with Imagination Station for K-12 outreach to the local community to promoting STEM.

Deaf Kids Code organization for creating light-following robot kits and support associated workshops in Indiana and Pennsylvania.

Activities at and an entry to the annual AgBOT Challenge event.

IMI/IN-MaC workshops to train local manufacturing and farming workforce on IoT and precision agriculture technologies developed by the ERC.

Workshops at the graduate fellow weekend, as part of the proposed Pathway to PhD Program, to bolster the number of successful graduate school and graduate fellowship applicants.

Workshops and events aligned with campus activities to promote agriculture and STEM, such as the Future Farmers of America annual meeting and National Robotics Week.

6. Graduate Fee Remissions
Graduate Fee Remissions are budgeted in accordance with university policy: $53,481 yr1, $54,874 yr2, $45,769 yr 3, 50,258 yr4, $31,936 yr5

I. Indirect Costs
Indirect costs are budgeted at the negotiated indirect cost rate of 57% of the modified total direct costs for research. This rate was approved on 10/03/2022 by the Department of Health and Human Services (POC: DHHS, Steven Zuraf, 301-492-4858).

M. Cost share

Dr. David Cappelleri, PI, 0.27 academic month each year 1-4, and 0.23 year 5. Dr. Cappelleri will be the Purdue site leader for the proposed ERC and will work on Thrust 1 on Agricultural sensor systems.

Dr. Dennis Buckmaster, co-PI, 0.27 academic month each year 1-4, and 0.23 year 5. Dr. Buckmaster will be the co-lead of Thrust 2 on Agricultural response systems.

Dr. Melba Crawford, co-PI, 0.27 academic month each year 1-4, and 0.23 year 5. Dr. Crawford will be working on research related to Thrust 1 on Agricultural sensor systems and Thrust 2 on Agricultural response systems..

Dr. James Krogmeier, co-PI, 0.27 academic month each year 1-4, and 0.23 year 5.Dr. Krogmeier will be working on research tasks as part of Thrust 3 on Communication and energy systems.

Dr. David Love, co-PI, is requesting 1 summer month each year 1-3, 0.75 year 4 and 0.50 year 5. Dr. Love will be the co-lead for Thrust 3 on Communication and energy systems.

Dr. Daniel Quinn, co-PI, 0.27 academic month each year 1-4, and 0.23 year 5. Dr. Quinn will be performing research tasks as part of Thrust 1 on Agricultural sensing systems.

TBA graduate students will be cost shared for 3 for 13 months year 1-2; 2 for 12 months year 3; 1 for 5 months year 4; 1 for 2 months year 5. These students will be assigned to work with PIs Love, Zhang, and/or Krogmeier to perform research tasks as part of Thrust 3.

Associated fringe benefits and indirect costs of the personnel effort being cost shared.
Graduate Fee Remissions are budgeted in accordance with university policy.

Total cost share per year; $224,949 yr1, $224,943 yr 2, $224,962 yr3, $149,965 yr4, $97,478 yr5

Year 1

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION	PROPOSAL NO.	DURATION (MONTHS)
University of Florida		Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Arnold	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
Dr. David Arnold	0.50	-	-	13,802	$
Dr. William Eisenstadt	0.50	-	-	7,295	
Dr. Alina Zare	0.50	-	-	12,233	
Dr. Sanjeev Koppal	0.50	-	-	6,879	
Dr. Vivek Sharma	0.50	-	-	5,752	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	2.00	-	-	33,990	
7. (9) TOTAL SENIOR PERSONNEL (1-6)	4.50	0.00	0.00	79,951	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	12.00	-	-	50,000	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (9) GRADUATE STUDENTS				299,133	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				18,333	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				447,417	
C. FRINGE BENEFITS (F CHARGED AS DIRECT COSTS)				71,476	
TOTALSAIARIES, WAGES AND FRINGE BENEFITS (A+ B+ C)				518,893	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				55,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1 STIPENDS $ ~~w89 9PR~~					
2 TRAVEL -					
3 SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS (3) TOTAL PARTICIPANT COSTS				30,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				52,928	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER - Describe Tuition and $10k in fabrication				165,660	
TOTAL OTHER DIRECT COSTS				218,588	
H. TOTAL DIRECT COSTS (A THROUGH G)				822,481	
I. INDIRECTCOSTS(F&A) (SPECIFYRATEAND BASE)					
52.5% [illegible]					
636,822 [illegible]					
TOTAL INDIRECT COSTS (F&A)				334,332	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,156,813	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				1,156,813	$

M. COST SHARING: PROPOSED LEVEL $231,362	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* David Arnold	DATE 8/8/24	FOR NSF USE ONLY
ORG. REP. TYPED NAME & SIGNATURE* Org. Rep. First & Last Name	DATE 8/8/24	INDIRECT COST RATE VERIFICATION DIV / Date Of Rate Sheet / FAIN / ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG 111C)

Year 2

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION University of Florida				PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR David Arnold				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
Dr. David Arnold	0.50	-	-	14,216	$
Dr. William Eisenstadt	0.50	-	-	7,514	
Dr. Alina Zare	0.50	-	-	12,600	
Dr. Sanjeev Koppal	0.50	-	-	7,085	
Dr. Vivek Sharma	0.50	-	-	5,925	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	2.00	-	-	35,010	
7. (9) TOTAL SENIOR PERSONNEL (1-6)	4.50	0.00	0.00	82,350	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	12.00	-	-	51,500	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (9) GRADUATE STUDENTS				309,429	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				14,163	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				457,442	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				71,994	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+ B + C)				529,436	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				37,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1.STIPENDS $ [redacted]					
2 TRAVEL				-	
3 SUBSISTENCE				-	
4 OTHER				-	
TOTAL NUMBER OF PARTICIPANTS (3) TOTAL PARTICIPANT COSTS				30,000	
G. OTHER DIRECT COSTS					
1 MATERIALS AND SUPPLIES				54,823	
2 PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3 CONSULTANT SERVICES				-	
4 COMPUTER SERVICES				-	
5 SUBAWARDS				-	
6 OTHER - Describe Tuition and $10k in fabrication				174,144	
TOTAL OTHER DIRECT COSTS				228,967	
H. TOTAL DIRECT COSTS (A THROUGH G)				825,403	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
52.5% MTDC 631,258 MTDC					
TOTAL INDIRECT COSTS (F&A)				331,410	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,156,813	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J OR (J MINUS K)				1,156,813	$
M. COST SHARING: PROPOSED LEVEL $231,363	AGREED LEVEL IF DIFFERENT: $				

PI/PD TYPED NAME AND SIGNATURE* David Arnold	DATE 8/8/24	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Org. Rep. First & Last Name	DATE 8/8/24	DATE / Date of Rate Sheet / Initials - ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG 111.C)

Year 3

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION: University of Florida	PROPOSAL NO. / DURATION (MONTHS)
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Arnold	AWARD NO.

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
Dr. David Arnold	0.50	-	-	14,642	$
Dr. William Eisenstadt	0.50	-	-	7,740	
Dr. Alina Zare	0.50	-	-	12,978	
Dr. Sanjeev Koppal	0.50	-	-	7,298	
Dr. Vivek Sharma	0.50	-	-	6,103	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	2.00	-	-	36,060	
7. (9) TOTAL SENIOR PERSONNEL (1-6)	4.50	0.00	0.00	84,821	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	12.00	-	-	53,045	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (9) GRADUATE STUDENTS				304,788	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. (1) SECRETARIAL- CLERICAL (IF CHARGED DIRECTLY)				14,587	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				457,241	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				72,539	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+ B+ C)				529,780	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				50,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1 STIPENDS $ 30,000					
2 TRAVEL -					
3 SUBSISTENCE -					
4 OTHER -					
TOTAL NUMBER OF PARTICIPANTS (3) TOTAL PARTICIPANT COSTS				30,000	
G. OTHER DIRECT COSTS					
1 MATERIALS AND SUPPLIES				41,035	
2 PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3 CONSULTANT SERVICES				-	
4 COMPUTER SERVICES				-	
5 SUBAWARDS				-	
6 OTHER- Describe Tuition and $10k in fabrication				174,821	
TOTAL OTHER DIRECT COSTS				215,856	
H. TOTAL DIRECT COSTS (A THROUGH G)				825,636	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
52.5% MTDC 630,814					
TOTAL INDIRECT COSTS (F&A)				331,177	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,156,813	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				1,156,813	$

M. COST SHARING: PROPOSED LEVEL $ 231,363	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* David Arnold	DATE 8/8/24	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Org. Rep. First & Last Name	DATE 8/8/24	DATE / ORG. CODE / NEW START / PREV. ORG.

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Year 4

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION: University of Florida	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Arnold	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (if Different)
Dr. David Arnold	0.50	-	-	15,082	$
Dr. William Eisenstadt	0.50	-	-	7,972	
Dr. Alina Zare	0.50	-	-	13,367	
Dr. Sanjeev Koppal	0.50	-	-	7,517	
Dr. Vivek Sharma	0.50	-	-	6,286	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	2.00	-	-	37,142	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	4.50	0.00	0.00	87,366	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	12.00	-	-	54,636	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	149,795	
3. (9) GRADUATE STUDENTS				-	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				15,025	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				306,822	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				55,675	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+ B+ C)				362,497	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				37,835	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1 STIPENDS $ 30,000					
2 TRAVEL -					
3 SUBSISTENCE -					
4 OTHER -					
TOTAL NUMBER OF PARTICIPANTS (3) TOTAL PARTICIPANT COSTS				30,000	
G. OTHER DIRECT COSTS					
1 MATERIALS AND SUPPLIES				21,558	
2 PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3 CONSULTANT SERVICES				-	
4 COMPUTER SERVICES				-	
5 SUBAWARDS				-	
6 OTHER - Describe Tuition and $ 10k in fabrication				92,577	
TOTAL OTHER DIRECT COSTS				114,135	
H. TOTAL DIRECT COSTS (A THROUGH G)				544,467	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 52.5% 431,889					
TOTAL INDIRECT COSTS (F&A)				226,742	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				771,209	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				771,209	$

M. COST SHARING: PROPOSED LEVEL $154,242	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* David Arnold	DATE 8/8/24	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Org. Rep. First & Last Name	DATE 8/8/24	Date Checked / Date of Rate Sheet / Initials - ORG

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*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG 111.C)

Year 5

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION University of Florida	PROPOSAL NO.		DURATION (MONTHS)		
			PROPOSED		GRANTED
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David Arnold	AWARD NO.				

A. SENIOR PERSONNEL: PI/PD, Co-Pis, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
Dr. David Arnold	0.50	-	-	15,534	$
Dr. William Eisenstadt	0.50	-	-	8,211	
Dr. Alina Zare	0.50	-	-	13,768	
Dr. Sanjeev Koppal	0.50	-	-	7,742	
Dr. Vivek Sharma	0.50	-	-	6,474	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	2.00	-	-	38,266	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	4.50	0.00	0.00	89,985	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	12.00	-	-	56,275	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (9) GRADUATE STUDENTS				55,806	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				15,476	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				217,542	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				45,922	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+ B+ C)				263,464	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				14,000	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1.STIPENDS $ 10 P.P.					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS (3) TOTAL PARTICIPANT COSTS				30,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				6,010	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER - Describe Tuition and $5k in fabrication				36,363	
TOTAL OTHER DIRECT COSTS				42,373	
H. TOTAL DIRECT COSTS (A THROUGH G)				349,837	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
52.5% * BASE 288,475 * RATE (%)					
TOTAL INDIRECT COSTS (F&A)				151,449	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				501,286	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				501,286	$
M. COST SHARING: PROPOSED LEVEL $ 100,257	AGREED LEVEL IF DIFFERENT: $				

PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY
David Arnold	8/8/24	INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked / Date of Rate Sheet / Initials - ORG
Org. Rep. First & Last Name	8/8/24	

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Cumulative

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY

ORGANIZATION	PROPOSAL NO.	DURATION (MONTHS)
University of Florida		Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	AWARD NO.	
David Arnold		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior Associates List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Personmonths CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
Dr. David Arnold	2.50	-	-	73,276	$
Dr. William Eisenstadt	2.50	-	-	38,732	
Dr. Alina Zare	2.50	-	-	64,946	
Dr. Sanjeev Koppal	2.50	-	-	36,521	
Dr. Vivek Sharma	2.50	-	-	30,540	
6. (4) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	10.00	-	-	180,458	
7. (9) TOTAL SENIOR PERSONNEL (1-6)	22.50	0.00	0.00	424,473	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POSTDOCTORAL ASSOCIATES	60.00	-	-	265,456	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	149,795	
3. (9) GRADUATE STUDENTS				969,156	
4. ( ) UNDERGRADUATE STUDENTS				-	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				77,584	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				1,886,464	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				317,606	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+ B+ C)				2,204,070	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				193,835	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $					
2. TRAVEL					
3. SUBSISTENCE					
4. OTHER					
TOTAL NUMBER OF PARTICIPANTS (3) TOTAL PARTICIPANT COSTS				150,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				176,354	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Describe Tuition and $45k in fabrication				643,565	
TOTAL OTHER DIRECT COSTS				819,919	
H. TOTAL DIRECT COSTS (A THROUGH G)				3,367,824	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
52.5% [redacted]					
2,619,258 [redacted]					
TOTAL INDIRECT COSTS (F&A)				1,375,110	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				4,742,934	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				4,742,934	$

M. COST SHARING: PROPOSED LEVEL $948,588	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* David Arnold	DATE 8/8/24	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Org. Rep. First & Last Name	DATE 8/8/24	Date / Date of Rate Sheet / Initials-ORG

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Budget Justification – University of Florida

Salary:
0.5 months support is requested in each year for the PI Dr. David Arnold (UF Site Director). Other senior personnel request salary support at 0.5 month/year as listed. All salary rates are based on current salaries.

Name	Role	Total Project Effort	Total Amount
Dr. Arnold	PI	2.5 Months	$73,276
Dr. Eisenstadt	Sr. Personnel	2.5 Months	$38,733
Dr. Zare	Sr. Personnel	2.5 Months	$64,944
Dr. Koppal	Sr. Personnel	2.5 Months	$36,522
Dr. Sharma	Sr. Personnel	2.5 Months	$30,540
Dr. Small	Sr. Personnel	2.5 Months	$24,998
Dr. Messina	Sr. Personnel	2.5 Months	$63,881
Dr. Stofer	Sr. Personnel	2.5 Months	$21,009
Dr. Summerlin	Sr. Personnel	2.5 Months	$70,569

Support is also requested to support Graduate Research Assistants, Postdoc, and Center Coordinator. Salaries are based on departmental averages, which vary by department/field.

All salaries are budgeted to increase by 3% each year.

Fringe rates are:

Faculty	30.1%
Grad Student	11.6%
Post Doc	11.6%
Teams Exempt (Staff)	37.7%

Travel:
Travel will be varied.
- *Domestic travel:* Domestic travel funds are requested for center participants to travel to the annual IoT4Ag summer retreats and annual NSF site visit meetings, and for faculty, students, and postdocs to attend and present research results at domestic technical conferences. Travel may also support Center leadership or faculty to meet with prospective industry, university and federal collaborators, members, and affiliates and also to attend meetings, conferences, or trade shows to promote/market the IoT4Ag Center. Travel may also support student travel to leadership development workshops, training/educational activities, and in support of intra-site ERC student exchanges between UF and Penn, UC Merced, and Purdue. In-state travel may also be required in support of center activities with regional partners.

- *Foreign travel:* Foreign travel funds are requested to enable faculty, students, and postdocs to attend and present research results at international technical conferences. Example conferences include:

- 2026 International Conference on Precision Agriculture, Rome, Italy, January 2026
- 2026 Intermag Conference, Manchester, UK, April 2026
- IEEE 12th World Forum on Internet of Things (WF-IoT), November 2026, Abu Dhabi, UAE
- IEEE International Conference on Robotics and Automation (ICRA), Seoul, Korea, May 2027
- Transducers 2027, Stockholm, Sweden, June 2027

Expenses:

- *Research expenses*: These may include: **[ARNOLD]** magnets, magnet wire, silicon wafers, antibodies/aptamers, bacteria, bacterial test kits, glassware, 3D printing costs, filament for 3D printing, optical imaging devices, and electronic measurement device, **[SUMERLIN]** biological reagents and materials for sensor functionalization (monomers, polymers, proteins, aptamers, lectins, peptides, antibodies), wires and electrical contacts, raw chemicals (solids, liquids, gasses), buffers, salts, nanomaterials, luminescent dyes, electroplating chemicals, and , general consumables (gloves, lab coats, Millipore filters), electrodes, and biomaterials each year for surface modification of biosensors, sample collection devices, biological growth media, AOAC-approved qPCR kits to validate sensor data, and funding for instrument user fees and analysis. **[ZARE/KOPPAL]** High Resolution RGB Camera, GPS-enabled Camera Trigger, Gimbal system, UAV replacement components (batteries, propellers), optical calibration materials (tarps, coded markers), optical components. **[SMALL/SHARMA]** Field supplies: seed, agrochemical products (e.g., pesticides, fertilizer) and plot supplies (e.g., electric fence, plot stakes), soil moisture sensors. Parts and supplies for UAS operations: supplies to build and maintain ground control points, temperature calibration plates, replacement batteries drones. Materials and supplies to construct and maintain spore traps. Laboratory supplies for inoculation, culture and identification of plant pathogens: growth media, Petri dishes, centrifuge tubes, DNA extraction kits, PCR reagents, sample preparation materials for sequencing. Data storage: LTO tapes for data archiving.
- *User facility expenses*: These may include on-campus user facility fees for machine time and staff assistance for the Research Service Centers (cleanroom, materials analysis, particle analysis), the Interdisciplinary Center for Biotechnology Research, the Soil and Water Sciences Diagnostic Labs, the Dept. of Chemistry Mass Spectrometry Research and Education Center, or other on-campus facilities. Rates vary by tool, but are typically ~$50/hr. Additional user facility expenses include field access costs at the NFREC. Land use fees are $1,000 per acre of peanuts and $2,200 per acre of citrus.
- *General center expenses*: Expenses may include printed publications such as brochures/flyers, sponsorship and advertising at technical conferences and trade meetings, professional memberships, website design/upgrades/maintenance/domain name fees, specialized design software, subscription fees, postage, shipping, photocopying, and other expenses associated with promotion and marketing of the IoT4Ag Center. Additional expenses may include office supplies, computers/tablets/displays/accessories, computer supplies, audio visual supplies, audio visual devices, publication subscriptions, general purpose software, electronic data subscriptions, honoraria, venue rental, audio/visual expenses, tables/chairs/podium rental, other rental fees, food and beverage, catering services, and other supplies in support of center activities.

- *Center Meeting expenses*: An additional $20,000 is budgeted in Year 2 (Year 7 of center) for UF to host the annual Center retreat meeting. Expenses may include office supplies, venue rental, audio/visual expenses, tables/chairs/podium rental, other rental fees, food and beverage, catering services, local transportation costs, publication costs, awards/commendations, entertainment expenses, entertainment services, event tickets, books and publications, linens, laundry services, and incidental costs.

Other Direct Costs:

- *Participant Support Costs*: $30,000/year is requested in each year to support three REU students per year.
- *Tuition:* Per University of Florida policy, all proposals that include salary support for graduate students must also include the appropriate tuition amount in the budget.

Facilities & Administration:

Indirect cost rates (IDC) are negotiated and determined by the U.S. Department of Health and Human Services. The University currently has an approved IDC rate of 52.5% of Modified Total Direct Costs (MTDC) for on-campus organized research

Cost Share Justification

We propose cost sharing of $948,588 which includes a portion of faculty salary, graduate student salary, associated employee benefits, NRF user fees, and unrecovered F&A.

Name	Role	Total Project Effort	Total Amount
Dr. Arnold	PI	2.58 Months	$74,774
Dr. Eisenstadt	Sr. Personnel	1.9 Months	$28,999
Dr. Zare	Sr. Personnel	1.9 Months	$48,623
Dr. Koppal	Sr. Personnel	1.9 Months	$27,343
Dr. Sharma	Sr. Personnel	1.9 Months	$22,865
Dr. Small	Sr. Personnel	1.9 Months	$18,716
Dr. Messina	Sr. Personnel	1.9 Months	$47,827
Dr. Summerlin	Sr. Personnel	1.9 Months	$52,834
TBD	Graduate Student	25.5 Months	$156,562

Fringe rates are:

Faculty	30.1%
Grad Student	11.6%

Total: $115,078

- *User facility expenses*: These may include on-campus user facility fees for machine time and staff assistance for the Research Service Centers (cleanroom, materials analysis, particle analysis), the Interdisciplinary Center for Biotechnology Research, the Soil and Water Sciences Diagnostic Labs, the Dept. of Chemistry Mass Spectrometry Research and Education Center, or other on-campus facilities. (28,403)

Facilities & Administration:

Indirect cost rates (IDC) are negotiated and determined by the U.S. Department of Health and Human Services. The University currently has an approved IDC rate of 52.5% of Modified Total Direct Costs (MTDC) for on-campus organized research. ($326,563)

Year 1

SUMMARY PROPOSAL BUDGET

ORGANIZATION Regents of the University of California, Merced				FOR NSF USE ONLY PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stefano Carpin				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Stefano Carpin (PI)	-	-	1.00	20,944	$
2. Erin Hestir (Co-PI)	-	-	1.00	15,833	
3. Lisa Yeo (Co-PI)	-	-	1.00	21,689	
4. Reza Ehsani (Co-PI)	-	-	1.00	19,322	
5. Catherine Keske (Senior Personnel)	-	-	1.00	18,411	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. (5) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	5.00	96,199	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (5) GRADUATE STUDENTS				250,813	
4. (6) UNDERGRADUATE STUDENTS				78,000	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				425,012	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				6,375	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				431,387	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,000	
2. FOREIGN				10,000	
F. PARTICIPANT SUPPORT 1. STIPENDS $ 33,000 2. TRAVEL 16,000 3. SUBSISTENCE - 4. OTHER 5,000					
TOTAL NUMBER OF PARTICIPANTS (33) TOTAL PARTICIPANT				54,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				13,070	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				4,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Software licenses, tuition and fees				83,487	
TOTAL OTHER DIRECT COSTS				100,557	
H. TOTAL DIRECT COSTS (A THROUGH G)				610,944	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 58.5% ← IDC % 483,458 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				282,823	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				893,767	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				893,767	$
M. COST SHARING: PROPOSED LEVEL $ 134,065	AGREED LEVEL IF DIFFERENT: $				
PI/PD TYPED NAME AND SIGNATURE* Stefano Carpin	DATE 8/9/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE* Ashley Moreno	DATE 8/9/2024			Date / Date of Rate Sheet / Initials-ORG	

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*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 2

SUMMARY PROPOSAL BUDGET

ORGANIZATION Regents of the University of California, Merced				FOR NSF USE ONLY PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stefano Carpin				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Stefano Carpin (PI)	-	-	1.00	21,573	$
2. Erin Hestir (Co-PI)	-	-	1.00	16,308	
3. Lisa Yeo (Co-PI)	-	-	1.00	22,340	
4. Reza Ehsani (Co-PI)	-	-	1.00	19,902	
5. Catherine Keske (Senior Personnel)	-	-	1.00	18,963	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. (5) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	5.00	99,086	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (5) GRADUATE STUDENTS				266,865	
4. (5) UNDERGRADUATE STUDENTS				66,950	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				432,901	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				6,493	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				439,394	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,000	
2. FOREIGN				10,000	
F. PARTICIPANT SUPPORT 1. STIPENDS $ 33,000 2. TRAVEL 16,000 3. SUBSISTENCE - 4. OTHER 5,000					
TOTAL NUMBER OF PARTICIPANTS (33) TOTAL PARTICIPANT				54,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,427	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				4,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER –Software licenses, tuition and fees				85,836	
TOTAL OTHER DIRECT COSTS				95,263	
H. TOTAL DIRECT COSTS (A THROUGH G)				613,657	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 58.5% ← IDC % 478,821 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				280,110	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				893,767	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				893,767	$
M. COST SHARING: PROPOSED LEVEL $134,065	AGREED LEVEL IF DIFFERENT: $				
PI/PD TYPED NAME AND SIGNATURE* Stefano Carpin	DATE 8/9/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE* Ashley Moreno	DATE 8/9/2024			Date / Date of Rate Sheet / Initials-ORG	

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*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 3

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
AWARD NO.		

ORGANIZATION: Regents of the University of California, Merced

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stefano Carpin

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior — List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Stefano Carpin (PI)	-	-	1.00	22,220	$
2. Erin Hestir (Co-PI)	-	-	1.00	16,798	
3. Lisa Yeo (Co-PI)	-	-	1.00	23,010	
4. Reza Ehsani (Co-PI)	-	-	1.00	20,499	
5. Catherine Keske (Senior Personnel)	-	-	1.00	19,532	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. (5) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	5.00	102,059	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (5) GRADUATE STUDENTS				283,943	
4. (3) UNDERGRADUATE STUDENTS				33,655	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				419,657	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				6,295	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				425,952	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				-	
2. FOREIGN				10,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 33,000					
2. TRAVEL 16,000					
3. SUBSISTENCE -					
4. OTHER 5,000					
TOTAL NUMBER OF PARTICIPANTS (33) TOTAL PARTICIPANT				54,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				8,768	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				4,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER –Software licenses, tuition and fees, retreat hosted at UCM				113,920	
TOTAL OTHER DIRECT COSTS				126,688	
H. TOTAL DIRECT COSTS (A THROUGH G)				616,640	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
58.5% ← IDC %					
473,721 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				277,127	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				893,767	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				893,767	$

M. COST SHARING: PROPOSED LEVEL $134,065 AGREED LEVEL IF DIFFERENT: $

PI/PD TYPED NAME AND SIGNATURE*	DATE	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
Stefano Carpin	8/9/2024			
ORG. REP. TYPED NAME & SIGNATURE*	**DATE**	**Date**	**Date of Rate Sheet**	**Initials-ORG**
Ashley Moreno	8/9/2024			

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Year 4

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: Regents of the University of California, Merced	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stefano Carpin	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior — List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Stefano Carpin (PI)	-	-	0.70	16,021	$
2. Erin Hestir (Co-PI)	-	-	0.70	12,111	
3. Lisa Yeo (Co-PI)	-	-	0.70	16,590	
4. Reza Ehsani (Co-PI)	-	-	0.70	14,780	
5. Catherine Keske (Senior Personnel)	-	-	0.70	14,083	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. (5) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	3.50	73,585	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (3) GRADUATE STUDENTS				145,016	
4. (3) UNDERGRADUATE STUDENTS				34,965	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				253,566	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,803	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				257,369	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,000	
2. FOREIGN				12,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 33,000					
2. TRAVEL 16,000					
3. SUBSISTENCE -					
4. OTHER 5,000					
TOTAL NUMBER OF PARTICIPANTS (33) TOTAL PARTICIPANT				54,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				11,463	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				4,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Software licenses, tuition and fees, and Annual Retreat Host				63,687	
TOTAL OTHER DIRECT COSTS				79,150	
H. TOTAL DIRECT COSTS (A THROUGH G)				417,519	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
58.5% ← IDC %					
304,831 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				178,326	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				595,845	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				595,845	$

M. COST SHARING: PROPOSED LEVEL $89,377	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* Stefano Carpin	DATE 8/9/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Ashley Moreno	DATE 8/9/2024	Date / Date of Rate Sheet / Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 5

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: Regents of the University of California, Merced	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stefano Carpin	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Stefano Carpin (PI)	-	-	0.50	11,787	$
2. Erin Hestir (Co-PI)	-	-	0.30	5,346	
3. Lisa Yeo (Co-PI)	-	-	0.30	7,323	
4. Reza Ehsani (Co-PI)	-	-	0.30	6,524	
5. Catherine Keske (Senior Personnel)	-	-	0.30	6,217	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. (5) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	1.70	37,197	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (2) GRADUATE STUDENTS				102,864	
4. (3) UNDERGRADUATE STUDENTS				36,334	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				176,395	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,646	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				179,041	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				-	
2. FOREIGN				15,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ -					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				10,659	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				10,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Software licenses, tuition and fees				45,537	
TOTAL OTHER DIRECT COSTS				66,196	
H. TOTAL DIRECT COSTS (A THROUGH G)				260,237	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
58.5% ← IDC %					
217,199 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				127,061	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				387,298	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				387,298	$

M. COST SHARING: PROPOSED LEVEL $58,095	AGREED LEVEL IF DIFFERENT: $	
PI/PD TYPED NAME AND SIGNATURE* Stefano Carpin	DATE 8/9/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION
ORG. REP. TYPED NAME & SIGNATURE* Ashley Moreno	DATE 8/9/2024	Date / Date of Rate Sheet / Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Cumulative

SUMMARY PROPOSAL BUDGET

ORGANIZATION Regents of the University of California, Merced				FOR NSF USE ONLY PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Stefano Carpin				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Stefano Carpin (PI)	-	-	4.20	92,545	$
2. Erin Hestir (Co-PI)	-	-	4.00	86,396	
3. Lisa Yeo (Co-PI)	-	-	4.00	90,952	
4. Reza Ehsani (Co-PI)	-	-	4.00	81,027	
5. Catherine Keske (Senior Personnel)	-	-	4.00	77,206	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. (5) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	20.20	408,126	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. (20) GRADUATE STUDENTS				1,049,501	
4. (20) UNDERGRADUATE STUDENTS				249,904	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				1,707,531	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				25,612	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				1,733,143	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				45,000	
2. FOREIGN				57,000	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ 132,000					
2. TRAVEL 64,000					
3. SUBSISTENCE -					
4. OTHER 20,000					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT COSTS				216,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				49,387	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				26,000	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Software licenses, tuition and fees, and Annual Retreat Host				392,467	
TOTAL OTHER DIRECT COSTS				467,854	
H. TOTAL DIRECT COSTS (A THROUGH G)				2,518,997	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
58.5% ← IDC %					
1,958,030 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				1,145,447	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				3,664,444	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				3,664,444	$
M. COST SHARING: PROPOSED LEVEL $549,667	AGREED LEVEL IF DIFFERENT: $				
PI/PD TYPED NAME AND SIGNATURE* Stefano Carpin	DATE 8/9/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. TYPED NAME & SIGNATURE* Ashley Moreno	DATE 8/9/2024			Date / Date of Rate Sheet / Initials-ORG	

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*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

NSF BUDGET JUSTIFICATION
University of California Merced

A. SENIOR PERSONNEL:

Dr. Stefano Carpin will commit 1 person month each in years 6-8, 0.7 in year 9, and 0.5 in year 10. He will serve as site director for UC Merced and will have oversight on all activities. Additionally, he will supervise graduate and undergraduate students working on research topics in Thrust 1 (robotics and sensors).

Dr. Erin Hestir will commit 1 person month each in years 6-8, 0.7 in year 9, and 0.3 in year 10. She will supervise graduate and undergraduate studens working on research in remote sensing as part of the research activities in Thrust 3. Dr. Hestir also will also serve on the IoT4Ag executive committee.

Dr. Lisa Yeo will commit 1 person month each in years 6-8, 0.7 in year 9, and 0.3 in year 10. She will supervise graduate and undergraduate students doing research in social and economic aspects of the technologies developed in the center (Thrust 3). Dr. Yeo will also serve as faculty co-lead for EWD activities.

Dr. Reza Ehsani will commit 1 person month each in years 6-8, 0.7 in year 9, and 0.3 in year 10. He will will supervise graduate and undergraduate students working on research topics in Thrust 1 (robotics and sensors). Dr. Ehsani will also serve as testbed co-lead and Thrust 1 co-lead.

Dr. Catherine Keske will commit 1 person month each in years 6-8, 0.7 in year 9, and 0.3 in year 10. She will supervise graduate and undergraduate students doing research in social and economic aspects of the technologies developed in the center (Thrust 3).

B. OTHER PERSONNEL:

The Graduate Student Researchers (TBD) 5 in year 6, 5 in year 7, 5 in year 8, 3 in year 9, and 2 in year 10 will each commit 9 person academic months at 50% effort per year and 3 person summer months at 100% effort per year. The GSRs will engage in research aligned with the projects submitted as part of the yearly research planning assessment cycles in the center.

The GSRs will work with each respective UCMerced Co-PI in order to deliver research findings in the areas of agricultural production, robotics, remote sensing, and socio-economic research projects. As much as possible, the Co-PIs will serve on the graduate student committees to facilitate cross-pollination of multidisciplinary **IoT4Ag** research and innovation. The GSRs will be recruited based upon potential promise as researchers, as well as potential contributions to cultivating a diverse and inclusive labor force, and for potential leadership in transferring **IoT4Ag** research and innovation post graduation, including possible continuance in the **IoT4Ag** program as post-doctoral fellow. All GSRs will attend **IoT4Ag** “boot camp” trainings held every alternate summer, to introduce new faculty and graduate and undergraduate students from all sites to smart agriculture, soil science, crop disease, water conservation and irrigation, energy, communication, and sensing systems, machine learning/artificial intelligence, robotics, and large-scale integration. The GSRs will be eligible to participate in a 2-week graduate research experience at ERC partner institutions, and an 8-week graduate student exchanges via University of Florida and

Colombian institutes (International Center for Tropical Agriculture, Universidad del Valle (Univalle), Corporación Biotec), as well as Brazilian institutions (Universidade Federal de Vicosa and Universidade de Sao Paulo).

The Undergraduate Student Researchers (TBD) 6 in year 6, 5 in year 7, 3 each in years 8-10 will each commit 10 hours per week during the 9 academic months per year and 20 hours per week during the 3 summer months per year. The Undergraduate Student Researcher will assist faculty and graduate students working on IoT4Ag research projects. Activities will include hardware and software development, assistance with data collection in the field, and other tasks on a per need basis.

IoT4Ag undergraduates will participate in intracampus and crosscampus research during the academic year as well as summer. These cohorts will establish an undergraduate research program to create synergy leading to the establishment of a capstone senior design course through ~6 capstone teams across all of the partner universities that will design, make, measure and model materials, devices, and systems that can be in used in agricultural applications. Through **IoT4Ag**, seniors at all of the partner universities will be brought together virtually during the capstone year to share the goals and outcomes of their projects and engage students in the breadth of problems and solutions that contribute to meeting the challenges of food, energy and water security.

Salaries are based on current actual salaries and are projected to include a 3% annual cost-of- living adjustment (and merit, if applicable) for Senior Personnel and Other Personnel, 3.5% annual cost-of-living adjustment for Postdoctoral Scholars effective each year and a 6.4% annual cost-of-living adjustment for Graduate Student Researchers each year, consistent with institutional policy. For the purposes of determining NSF's 2-month annual effort limit on senior personnel compensation, UC Merced defines a "year" as the organization's fiscal year that spans from July 1 – June 30.

C. FRINGE BENEFITS:

a. 1.5% benefit rate is used for PI/Co-PIs/Senior Personnel.

b. 1.5% benefit rate is used for Graduate Student Researchers and Undergraduate Student Researchers.

The University of California, Merced Composite Fringe Benefit Rates (CFBR) have been reviewed and federally approved by the Department of Health and Human Services (DHHS) for use by all fund sources for FY23. Rates beyond June 30, 2023 are estimates and are provided for planning purposes only. Future CFBR rates are subject to review and approval by DHHS on an annual or bi-annual basis. Fringe benefits are assessed as a percentage of the respective employee's salary. *For more information, please see: https://finance.ucmerced.edu/costing-policy-analysis/composite-benefit-rates-0*

D. TRAVEL:

Domestic**:** Funding is requested for domestic travel for PI, Co-I's and Senior Personnel to attending an annual retreat at collaborator institutes as well as site visits. No travel in Year 8, due to UC Merced hosting and no travel in year 10 as the project winds down. Estimated breakdown of costs are as follows:

Item	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Airfare	$5,000	$5,000	$0	$5,000	$0	$15,000
Lodging	$5,000	$5,000	$0	$5,000	$0	$15,000
Meals	$3,000	$3,000	$0	$3,000	$0	$9,000
Transportation	$2,000	$2,000	$0	$2,000	$0	$6,000
TOTAL:	$15,000	$15,000	$0	$15,000	$0	$45,000

D.1. Foreign**:** Funding is requested for foreign travel for faculty and graduate students presenting research findings at leading international conferences in areas relevant to the IoT4Ag effort. As research progresses and the number of papers increases, these expenses are corresponginly scheduled to increase. Leading international conferences are often held in Asia and/or Europe and estimated breakdown of costs are as follows:

Item	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Airfare	$4,000	$4,000	$4,000	$5,000	$6,000	$23,000
Lodging	$3,000	$3,000	$3,000	$3,500	$4,500	$17,000
Meals	$1,000	$1,000	$1,000	$1,000	$1,500	$5,500
Conference Registration	$1,000	$1,000	$1,000	$1,500	$2,000	$6,500
Transportation	$1,000	$1,000	$1,000	$1,000	$1,000	$5,000
TOTAL:	$10,000	$10,000	$10,000	$12,000	$15,000	$57,000

International per diem rates can be found here: https://aoprals.state.gov/web920/per_diem.asp

E. PARTICIPANT SUPPORT COSTS: 132 participants total

E.1. Stipends – $28,000 is budgeted each year for years 6-9 for graduate student training stipends to deliver courses on precision agriculture, remote sensing, robotics, and sustainable agriculture during the CalTeach summer youth workshops. The stipend will be available to participating **IoT4Ag** students from any of the campuses. CalTeach stipend =$500/week, for approximately 14 students per year.

E.2. Stipends - A budget of $5,000 per year for Years 6-9 funds are earmarked to support Community College Research Placements. This summer program facilitates the placement of Central Valley community college students in IoT4Ag ERC research laboratories at UC Merced, providing students with hands-on experience in cutting-edge agricultural research while fostering collaboration between UC Merced and neighboring community colleges. By immersing these students in real-world research projects, they gain invaluable skills, mentorship, and exposure to diverse career pathways in agriculture, ranging from soil science to drones and robotics. This program not only addresses the critical need for skilled professionals in the agricultural sector but promotes diversity and inclusivity in STEM fields by providing access to underrepresented communities. Through mentorship, training, and networking opportunities, we empower the next generation of agricultural leaders and innovators while strengthening partnerships between UC Merced and surrounding community colleges. Two students will receive stipends each year. $5,000x4=$20,000

E.3. Travel – $16,000 is budgeted each year for years 6-9 for a Technical Exchange meeting, for undergraduate and graduate **IoT4Ag** student to travel, at about 6 trips per

year from all 4 campuses, to participate in CalTeach training, to conduct field trials, and to participate in workforce development exercises with agricultural producers in California's Central Valley. This travel budget also covers seminar and workshop participation in groups such as CITRIS's Ag Women in Tech. The travel budget also includes student travel to **IoT4Ag** annual meetings. Appoximentely 16 students will receive around $1,000 per year.

E.4. F.3 Other – $5,000 is budgeted each year for years 6-9. A budget of $5,000 per year for Years 6-9 funds are earmarked to support IoT4Ag's nascent MSI Research Scholars initiative. This program pairs a junior tenure-track faculty member at a minority serving institution with an IoT4Ag faculty researcher to collaborate and advance the visiting scholar's research program. The MSI Research Scholars initiative is becoming a signature ERC activity with the goal of increasing the success of junior faculty in attracting research funds and achieving tenure, especially among women and URM groups. IoT4Ag will provide a travel allowance and research stipend to one MSI Research Scholar each year. $5,000x4=$20,000

F. OTHER DIRECT COSTS:

F.1. Materials and Supplies: Funding is requested for purchasing laboratory consumables and supplies. These include cables, batteries, tools and hardware needed to develop and maintain the sytems to perform the various research projects part of the IoT4Ag research portfolio.

F.2. Publication Costs/Documentation/Dissemination: Funding is requested for to paying *OpenAccess* fees for journal papers produced as part of the center research activities.

F.3. Tuition and fees: The University of California, Merced provides full remission of tuition, all fees, and graduate student health insurance to all graduate students who are employed on-campus at 25% time or greater during the academic year. The rates are based on current graduate fees and are escalated annually in the budget at a rate of 10% per year. Additional information regarding the fee remission program can be found at: https://catalog.ucmerced.edu/content.php?catoid=23&navoid=2423

F.4. Other: Software licenses will be required for all research threads (agricultural production and sensors, robotics, remote sensing, and socio-economic analysis). Laptop and desktop computers are requested for the PIs and/or students working on the projects and performing computational work.

F.5. Other: Funding is requested for hosting an annual retreat at UC Merced in year 8 and will be used for renting the conference facility and support the activities part of the yearly retreat (e.g., transportation costs to visit relevant sites, support of the graduate student activities, meals, etc.).

G. INDIRECT COSTS:

Indirect costs are based on University negotiated rates with the cognizant federal authority and are applied at a rate of 58.5% for the entire project period using the modified total direct cost (MTDC) formula as per the approved rate agreement dated 12/05/2022. Modified total direct costs exclude equipment, capital expenditures, charges for patient care, student tuition remission, rental costs of off-site facilities, scholarships, fellowships, participant support costs, as well as the portion of each subgrant and subcontract in excess of $25,000. For more information, please see:
https://ucmerced.app.box.com/s/wfp5qp3nz8v24kcvj0zrk0umr2vccuf5

Cost Share:

SENIOR PERSONNEL:

Dr. Stefano Carpin will commit 0.53 person months in year 6, 0.50 in year 7, 0.47 in year 8, 0.31 in year 9, and 0.19 in year 10. He will serve as site director for UC Merced and will have oversight on all activities. Additionally, he will supervise graduate and undergraduate students working on research topics in Thrust 1 (robotics and sensors).

Dr. Erin Hestir will commit 0.53 person months in year 6, 0.50 in year 7, 0.47 in year 8, 0.31 in year 9, and 0.19 in year 10. She will supervise graduate and undergraduate studens working on research in remote sensing as part of the research activities in Thrust 3. Dr. Hestir also will also serve on the IoT4Ag executive committee.

Dr. Lisa Yeo will commit 0.53 person months in year 6, 0.50 in year 7, 0.47 in year 8, 0.31 in year 9, and 0.19 in year 10. She will supervise graduate and undergraduate students doing research in social and economic aspects of the technologies developed in the center (Thrust 3). Dr. Yeo will also serve as faculty co-lead for EWD activities.

Dr. Reza Ehsani will commit 0.53 person months in year 6, 0.50 in year 7, 0.47 in year 8, 0.31 in year 9, and 0.19 in year 10. He will will supervise graduate and undergraduate students working on research topics in Thrust 1 (robotics and sensors). Dr. Ehsani will also serve as testbed co-lead and Thrust 1 co-lead.

Dr. Catherine Keske will commit 0.53 person months in year 6, 0.50 in year 7, 0.47 in year 8, 0.31 in year 9, and 0.19 in year 10. She will supervise graduate and undergraduate students doing research in social and economic aspects of the technologies developed in the center (Thrust 3).

FRINGE BENEFITS:
1.5% benefit rate is used for PI/Co-PIs/Senior Personnel.

OTHER DIRECT COSTS:
Tuition and fees: 25% of annual tuition and fees for Graduate Student Researchers.
Y6: $24,496, Y7: $26,945, Y8: 29,640, Y9: $19,562, Y10: $14,346. Total: $114,989

INDIRECT COSTS:
Unrecovered Indirect Costs based on University negotiated rates with the cognizant federal authority and are applied at a rate of 58.5% for the entire project period using the modified total direct cost (MTDC) formula as per the approved rate agreement dated 12/05/2022.
Y6: $40,440, Y7: $39,536, Y8: $38,542, Y9: $25,768, Y10: $16,147. Total: $160,433

Year 1

SUMMARY PROPOSAL BUDGET				FOR NSF USE ONLY		
ORGANIZATION Arizona State University				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Ayesha Boyce				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. Ayesha Boyce		0.27	0.50	9,256	$	
2.	-	-	-	-		
3.	-	-	-	-		
4.	-	-	-	-		
5.	-	-	-	-		
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-		
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.27	0.50	9,256		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-		
3. ( ) GRADUATE STUDENTS				-		
4. (1) UNDERGRADUATE STUDENTS				14,880		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				-		
TOTAL SALARIES AND WAGES (A + B)				24,136		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,914		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				27,050		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,011		
2. FOREIGN				-		
F. PARTICIPANT SUPPORT						
1. STIPENDS $ -						
2. TRAVEL -						
3. SUBSISTENCE -						
4. OTHER -						
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				-		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				-		
6. OTHER – CopyEditing				245		
TOTAL OTHER DIRECT COSTS				245		
H. TOTAL DIRECT COSTS (A THROUGH G)				36,306		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)						
57.0% ← IDC %						
36,306 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				20,694		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				57,000		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				57,000	$	
M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* Ayesha Boyce Ayesha Boyce	DATE 8/1/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Amber Martin	DATE 8/1/2024			Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 2

SUMMARY PROPOSAL BUDGET				FOR NSF USE ONLY		
ORGANIZATION Arizona State University				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Ayesha Boyce				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. Ayesha Boyce	-	0.27	0.50	9,534	$	
2.	-	-	-	-		
3.	-	-	-	-		
4.	-	-	-	-		
5.	-	-	-	-		
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-		
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.27	0.50	9,534		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-		
3. ( ) GRADUATE STUDENTS				-		
4. (1) UNDERGRADUATE STUDENTS				15,326		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				-		
TOTAL SALARIES AND WAGES (A + B)				24,860		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,091		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				27,951		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				8,328		
2. FOREIGN				-		
F. PARTICIPANT SUPPORT						
1. STIPENDS $ -						
2. TRAVEL -						
3. SUBSISTENCE -						
4. OTHER -						
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				27		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				-		
6. OTHER – Copy Editing				-		
TOTAL OTHER DIRECT COSTS				27		
H. TOTAL DIRECT COSTS (A THROUGH G)				36,306		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)						
57.0% ← IDC %						
36,306 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				20,694		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				57,000		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				57,000	$	
M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* Ayesha Boyce Ayesha Boyce	DATE 8/1/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Amber Martin	DATE 8/1/2024	Date	Date of Rate Sheet	Initials-ORG		

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 3

SUMMARY PROPOSAL BUDGET

ORGANIZATION	FOR NSF USE ONLY		
Arizona State University	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Ayesha Boyce	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Ayesha Boyce	-	0.27	0.50	9,820	$
2.	-	-	-	-	
3.	-	-	-	-	
4.	-	-	-	-	
5.	-	-	-	-	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.27	0.50	9,820	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. ( ) GRADUATE STUDENTS				-	
4. (1) UNDERGRADUATE STUDENTS				15,786	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				25,606	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,279	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				28,885	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				7,172	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ -					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				249	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Copy Editing				-	
TOTAL OTHER DIRECT COSTS				249	
H. TOTAL DIRECT COSTS (A THROUGH G)				36,306	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
57.0% ← IDC %					
36,306 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				20,694	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				57,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				57,000	$

M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE* Ayesha Boyce	DATE 8/1/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Amber Martin	DATE 8/1/2024	Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 4

SUMMARY PROPOSAL BUDGET

FOR NSF USE ONLY		
ORGANIZATION: Arizona State University	PROPOSAL NO.	DURATION (MONTHS): Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Ayesha Boyce	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)
1. Ayesha Boyce	-	0.27	0.50	10,115	$
2.	-	-	-	-	
3.	-	-	-	-	
4.	-	-	-	-	
5.	-	-	-	-	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-	
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.27	0.50	10,115	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-	
3. ( ) GRADUATE STUDENTS				-	
4. (1) UNDERGRADUATE STUDENTS				8,130	
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-	
6. ( ) OTHER – Describe				-	
TOTAL SALARIES AND WAGES (A + B)				18,245	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,328	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				21,573	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				-	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,342	
2. FOREIGN				-	
F. PARTICIPANT SUPPORT					
1. STIPENDS $ -					
2. TRAVEL -					
3. SUBSISTENCE -					
4. OTHER -					
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				410	
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-	
3. CONSULTANT SERVICES				-	
4. COMPUTER SERVICES				-	
5. SUBAWARDS				-	
6. OTHER – Copy Editing				-	
TOTAL OTHER DIRECT COSTS				410	
H. TOTAL DIRECT COSTS (A THROUGH G)				24,325	
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)					
57.0% ← IDC %					
24,325 ← IDC Base					
TOTAL INDIRECT COSTS (F&A)				13,865	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				38,190	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				38,190	$

M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $			
PI/PD TYPED NAME AND SIGNATURE* Ayesha Boyce	DATE 8/1/2024	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Amber Martin	DATE 8/1/2024	Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Year 5

SUMMARY PROPOSAL BUDGET

ORGANIZATION Arizona State University				FOR NSF USE ONLY PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Ayesha Boyce				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. Ayesha Boyce	-	-	0.30	4,059	$	
2.	-	-	-	-		
3.	-	-	-	-		
4.	-	-	-	-		
5.	-	-	-	-		
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)	-	-	-	-		
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	0.00	0.00	0.30	4,059		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-		
3. ( ) GRADUATE STUDENTS				-		
4. (1) UNDERGRADUATE STUDENTS				8,374		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				-		
TOTAL SALARIES AND WAGES (A + B)				12,433		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				1,473		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				13,906		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				-		
2. FOREIGN				-		
F. PARTICIPANT SUPPORT						
1. STIPENDS $ -						
2. TRAVEL -						
3. SUBSISTENCE -						
4. OTHER -						
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				-		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				-		
6. OTHER – Copy Editing				2,391		
TOTAL OTHER DIRECT COSTS				2,391		
H. TOTAL DIRECT COSTS (A THROUGH G)				16,297		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)						
57.0% ← IDC %						
16,297 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				9,289		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				25,586		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				25,586	$	
M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* Ayesha Boyce Ayesha Boyce	DATE 8/1/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Amber Martin	DATE 8/1/2024			Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions* *SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Cumulative

SUMMARY PROPOSAL BUDGET				FOR NSF USE ONLY		
ORGANIZATION Arizona State University				PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: Ayesha Boyce				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PIs, Faculty and Other Senior List each separately with name and title. (A.7. Show number in brackets)	NSF-Funded Person-months CAL	 ACAD	 SUMR	Funds Requested By Proposer	Funds Granted by NSF (If Different)	
1. Ayesha Boyce	-	1.08	2.30	42,784	$	
2.	-	-	-	-		
3.	-	-	-	-		
4.	-	-	-	-		
5.	-	-	-	-		
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION	-	-	-	-		
7. ( ) TOTAL SENIOR PERSONNEL (1-6)	1.08	1.08	2.30	42,784		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( ) POSTDOCTORAL ASSOCIATES	-	-	-	-		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	-	-	-	-		
3. ( ) GRADUATE STUDENTS				-		
4. (1) UNDERGRADUATE STUDENTS				62,496		
5. ( ) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				-		
6. ( ) OTHER – Describe				-		
TOTAL SALARIES AND WAGES (A + B)				105,280		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				14,085		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				119,365		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				-		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				26,853		
2. FOREIGN				-		
F. PARTICIPANT SUPPORT 1. STIPENDS $ - 2. TRAVEL - 3. SUBSISTENCE - 4. OTHER -						
TOTAL NUMBER OF PARTICIPANTS ( ) TOTAL PARTICIPANT				-		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				686		
2. PUBLICATION/DOCUMENTATION/DISSEMINATION				-		
3. CONSULTANT SERVICES				-		
4. COMPUTER SERVICES				-		
5. SUBAWARDS				-		
6. OTHER – Copy Editing				2,636		
TOTAL OTHER DIRECT COSTS				3,322		
H. TOTAL DIRECT COSTS (A THROUGH G)				149,540		
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE) 57.0% ← IDC % 149,540 ← IDC Base						
TOTAL INDIRECT COSTS (F&A)				85,236		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				234,776		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECT SEE GPG II.D.7.j.)				-		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				234,776	$	
M. COST SHARING: PROPOSED LEVEL $	AGREED LEVEL IF DIFFERENT: $					
PI/PD TYPED NAME AND SIGNATURE* Ayesha Boyce Ayesha Boyce	DATE 8/1/2024			FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. TYPED NAME & SIGNATURE* Amber Martin	DATE 8/1/2024			Date	Date of Rate Sheet	Initials-ORG

NSF Form 1030 (10/99) *Supersedes All Previous Editions*

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.C)

Budget Justification
Arizona State University; PI Ayesha Boyce

A. Senior Personnel $42,784

Principal Investigator Ayesha Boyce, PhD, Associate Professor, MLF Teachers College will dedicate 0.27 Academic Year months and 0.5 Summer Months in Y6-Y9. She will dedicate 0.3 Summer months in Y10. Dr. Boyce will collect, analyze and report on evaluation data.

B. Other Personnel $62,496
An Hourly Student will be hired to assist with the research and will also collect and analyze data. they will be paid $31/hr for up to 10 hours per week for 48 weeks of the calendar year in Y6-Y8. The student hours will be reduced to 5 hours per week for 48 weeks in Y9-Y10. The student will assist with the evaluation.

An estimated cost escalation has been included in the out years, consistent with ASU policy.

"Defining of a year": ASU has defined a "year" as a calendar year for senior personnel and will apply this term "year" consistently across all NSF-funded grants.

C. Fringe Benefits $14,085

Arizona State University defines fringe benefits as direct costs, estimates benefits as a standard percent of salary applied uniformly to all types of sponsored activities, and charges benefits to sponsors in accordance with the federally-negotiated rates in effect at the time salaries are incurred. The rates used in the proposal budget are based on the current federally-negotiated rate agreement. An estimated cost escalation has been included in the out years, consistent with ASU policy. The applicable approved rates are:

Fiscal Year	Faculty	Hourly Students
FY2026	28.75%	1.70%
FY2027	29.61%	1.75%
FY2028	30.50%	1.80%
FY2029	31.42%	1.85%
FY2030	32.36%	1.91%

D. Equipment (N/A)

E. Travel Costs $26,853

Domestic Annual Meeting/Retreat Travel
This project includes travel to annual project meetings which will take place at Purdue (Indiana) in Y6, University of Florida in Y7, Merced (California) in Y8 and University of Pennsylvania in

Y9. Travel for two persons (PI and Student) is included to these locations at the GSA rates in each of these years. The breakdown of the costs for two travelers are below:

Destination: Lafayette / West Lafayette, Indiana Y6

Roundtrip airfare ($600 x 2)	$1,200
Lodging *(2 nights at a rate of $118/night = $236 per person)*	$472
Per diem *(3 days at a rate of $54/day = $162 per person)*	$324
Ground Transportation ($150 x 2)	$300
Concur Fee ($11 x 2)	$22
Total	**$2,318**

Destination: St. Augustine, Florida Y7

Roundtrip airfare	$1,400
Lodging *(2 nights at a rate of $159/night = $318 per person)*	$636
Per diem *(3 days at a rate of $59/day = $177 per person)*	$354
Ground Transportation ($150 x 2)	$300
Concur Fee ($11 x 2)	$22
Total	**$2,712**

Destination: Sacramento, California Y8

Roundtrip airfare ($600 x 2)	$1,200
Lodging *(2 nights at a rate of $145/night = $290 per person)*	$580
Per diem *(3 days at a rate of $59/day = $177)*	$354
Ground Transportation ($150 x 2)	$300
Concur Fee ($11 x 2)	$22
Total	**$2,456**

Destination: Pittsburgh, Pennsylvania Y9

Roundtrip airfare ($600 x 2)	$1,200
Lodging *(2 nights at a rate of $124/night = $248 per person)*	$496
Per diem *(3 days at a rate of $54/day = $162 per person)*	$324
Ground Transportation ($150 x 2)	$300
Concur Fee ($11 x 2)	$22
Total	**$2,342**

Domestic Project Travel

Purpose: Costs for project travel to the University of Pennsylvania for site visits to present findings and data colelction is included in Y6-Y8 of the project for the Principal Investigator. The breakdown of costs for a single trip is below:

Destination: Pittsburgh, Pennsylvania

Roundtrip airfare	$650
Lodging *(2 nights at a rate of $124/night)*	$248
Per diem *(3 days at a rate of $54/day)*	$162
Ground Transportation	$200
Concur Fee	$11
Total per trip:	**$1,271**

$1,271 x 3 = $3,813

Domestic Conference Travel

Purpose: Costs for dissemination of project results at an annual conference (American Evaluator Association) is also included for the Principal Investigator in Y6-Y8 with some travel funds for the student included in Y6 & Y7 of the project. An estimated breakdown of these costs is below:

Destination: Washington, DC used to estimate as actual location is TBD.

Roundtrip airfare	$700
Lodging *(3 nights at a rate of $258/night)*	$774
Per diem *(4 days at a rate of $69/day)*	$276
Ground Transportation	$200
Registration Fee	$750
Concur Fee	$11
Total per trip:	**$2,711**

$2,711 x 3 = $8,133

Funds for student travel to the AEA conference are also included at $2,711 in Y6, $1,634 in Y7 and $734 in Y8 for a total of $5,079.

All lodging and per diem meal rates are based on maximum rates established by ASU's travel guide, which sets rates at or below those established by the General Services Administration (GSA) and U.S. Department of State. ASU's travel system software provider, Concur Technologies, assesses a charge of $11 per person for each travel expense report submitted. The expense is a direct cost charged per trip.

F. Participant Support (N/A)

G. Other Direct Costs: $3,322

Other Services: Copy Editing
Funds in each year will be used towards copy editing for evaluation reports.

H. Total Direct Costs: $149,540

I. Facilities and Administrative Costs (Indirect Costs): $85,236

ASU's Facilities and Administrative cost rates (F&A, indirect costs) have been approved by the US Department of Health and Human Services. The current Federally-approved Rate Agreement is dated May 24, 2023. The F&A for this proposed budget has been calculated at 57% Modified Total Direct Costs (MTDC) in accordance with program guidelines.

The MTDC base includes salaries and benefits, travel, and other direct costs. Excluded costs include capital equipment, participant support, student tuition remission, and subaward costs in excess of $25,000.

J. Total Amount Requested: $234,776

APPENDIX XIV. SUPPLEMENTAL MATERIALS

The supplemental materials for the YR5 IoT4Ag Annual Report begin on the next page and include the following:

- IoT4Ag Financial Support Commitment Letter
- In-Kind Contribution Letter (Agribugs)
- IRB Approval
- Engineering Workforce Development Additional Tables
- SWOT Analysis Reports
    - Scientific Advisory Board (SAB)
    - Industrial Practitioner (IPAB) / Agricultural Systems (ASAB) Advisory Board
    - Engineering Workforce Development (EWD) / Diversity & Culture of Inclusion (DCI) Advisory Board
    - Student & Postdoc Leadership Council (SPLC)

Office of the Vice Provost for
RESEARCH
University of Pennsylvania

September 30, 2024

The University of Pennsylvania is proud to serve as the lead institution of the NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag). IoT4Ag is aligned with the University of Pennsylvania's new strategic framework, "in principle and practice". The framework describes the university initiatives to be anchored, interwoven, inventive, and engaged, uniting diverse communities and disciplines to create understanding and solutions and to lead in addressing the planet's climate, one of the great challenges of our time. IoT4Ag is a leading Center in Penn Engineering and is synergistic with the School's strategic initiative on Energy and Sustainability and its commitment to education, diversity and inclusion, and innovation.

Our engineering dean, Vijay Kumar, is an active investigator in the IoT4Ag research agenda. Therefore, to manage the conflict of interest in developing a sustainability plan for the Center, I serve as chair of the Dean's council for the IoT4Ag Center. In this role, I provide detail on the support provided by the university to grow and sustain the Center beyond the next phase of funding.

As the lead institution, Penn is committed to IoT4Ag's continued success and is pleased to support the Center through renewal and as it becomes self-sustaining after NSF support concludes.

- IoT4Ag will soon be relocated to a new and permanent headquarters space in Penn Engineering's complex. This will be a newly renovated administrative and collaborative workspace. Locating IoT4Ag within Penn Engineering's main complex, which itself is located within the campus core, is an exceptional location to embed the Center within Penn.
- IoT4Ag will retain dedicated lab space for the fabrication and testing of novel agricultural and environmental sensors in the new Vagelos Laboratory for Energy Science and Technology.
- Penn Engineering will support a research assistant seed fellowship, at one fellowship per year, to facilitate new research connections between IoT4Ag and the Penn campus.
- Penn will guarantee support for the transition of trainees supported by the grant in the final two years when the NSF funds decrease. This will ensure that their support remains as new support is acquired.
- Penn will support the remainder of the Administrative Director salary (25% effort in Year 9, 50% effort in Year 10, and at 100% effort for three following years) and the Education and Inclusivity Director salary (25% effort in Year 9 and 50% effort in Year 10) to continue the momentum of IoT4Ag through graduation to being self-sustaining.
- We have designated the IoT4Ag Center as a Penn Engineering Research Center, providing a mechanism to return 15% of the indirect costs from the Center activities under the ERC program, and as it secures multidisciplinary grants from industry, foundations, and other agencies as it becomes a self-sustaining Center.

1 College Hall, Suite G08 Philadelphia, PA 19104-6303
Tel 215-898-7236 Fax 215-573-2108 http://www.research.upenn.edu

- As part of its designation as a Penn Engineering Research Center, the Center faculty will have full access to a strategic support team that will facilitate additional large grant submissions to other federal agencies and cultivate partnerships with industry and foundations.
- We will prioritize our efforts to support IoT4Ag and develop strong relationships with the state of Pennsylvania through our government relations office.

In conclusion, Penn is proud of IoT4Ag's success to date and excited to support the future IoT4Ag so it can "*create and translate to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come.*"

Sincerely,

Dawn A. Bonnell, PhD
Senior Vice Provost for Research
Henry Robinson Towne Professor of Engineering and Applied
Science Materials Science and Engineering

1 College Hall, Suite G08 Philadelphia, PA 19104-6303
Tel 215-898-7236 Fax 215-573-2108 http://www.research.upenn.edu



726 N Meridian St.
Tallahassee, FL 32303
(786) 897-2050
Agribugs.com
Darren@agribugs.com

Dear IoT4AG,

This letter is in reference to our in-kind contribution to working with Dr. Ian Small's group on the Sentinel project located at the North Florida Research and Agricultural Center. We are conducting research and development services on micro drones and video data processing.

Faculty member: Dr. Ian Small

Project: Sentinel 18 and 32 spray systems

Materials: Micro Drone / Agisoft license

Provided: 7/12/2024 (8/24 – 7/25)

Value: $2,500 for hardware and data processing services.

Thank you,

Darren Raj
Research and Development
(786) 897-2050

ASU Knowledge Enterprise Development

EXEMPTION GRANTED

Ayesha Boyce
Division of Educational Leadership and Innovation - Tempe
-
Ayesha.Boyce@asu.edu

Dear Ayesha Boyce:

On 12/1/2022 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Evaluation of IoT4Ag
Investigator:	Ayesha Boyce
IRB ID:	STUDY00017082
Funding:	Name: National Science Foundation, Grant Office ID: FP00034804, Funding Source ID: 1941529
Grant Title:	FP00034804;
Grant ID:	FP00034804;
Documents Reviewed:	• Consent_Form_IoT4AgEvaluation_12_01_2022.pdf, Category: Consent Form; • Instruments_Surveys_IoT4AgEvaluation_11_28_2022.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • IRB Correspondance 12-01-2022, Category: Other; • IRB Social Behavioral - IoT4Ag - 12_01_2022.docx, Category: IRB Protocol; • Recruitment_Email_IoT4AgEvaluation_11_30_2022.pdf, Category: Recruitment Materials; • SOW, Category: Sponsor Attachment;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2)(ii) Tests, surveys, interviews, or observation (low risk) on 12/1/2022.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

If any changes are made to the study, the IRB must be notified at research.integrity@asu.edu to determine if additional reviews/approvals are required. Changes may include but not limited to revisions to data collection, survey and/or interview questions, and vulnerable populations, etc.

Sincerely,

IRB Administrator

cc: Caitlin Albrechtsen
Caitlin Albrechtsen
Mohammed Ibrahim

ENGINEERING WORKFORCE DEVELOPMENT – ADDITIONAL TABLES

Appendix Table 4E.1. 2024 IoT4Ag REU Participants

Name	**Major**	**Home Institution** **Bold** = non-R1, R2 or Minority Serving**	**IoT4Ag Host**
Angulo, Liani M.[1a]	Mechanical Eng	**Merced College (CC, HSI)**	UC Merced
Brassington, Cole	Computer Science	Villanova Univ	Penn
Chopra, Samarth	Computer & Systems Eng	Univ of Pittsburgh	Penn
Ciccone, Matthew	Bioengineering & Biomedical Eng	Princeton	UF
Guin, Anika	Computer Science	The Univ of Texas at Dallas	UF
Hernandez, Austin[1a]	Mechanical Eng	**Merced College (CC, HSI)**	UC Merced
Holland, Amelia	Eng, General	Swarthmore College	Penn
Houchen, Solomon[1b]	Botany	**Santa Fe College (CC)**	Purdue
Inkeles, Tyler	Chemistry	**California Polytechnic State Univ San Luis Obispo (AANAPISI)**	UF
Luna, Ismael[1b]	Electrical & Computer Eng	**The Univ of Texas at El Paso (HSI)**	Purdue
Medina-Tirado, Ivanellys	Microbio Sci & Immunology	**Univ of Puerto Rico at Humacao (HSI)**	Penn
Mody, Rohan[1c]	Chemistry	Illinois Institute of Technology	Penn
Moujalled, Yazlin	Computer Programming	**Univ of Maryland Baltimore County (AANAPISI)**	Penn
Petersen, Claire	Biomedical Eng	Northwestern Univ	Penn
Platon, Alexandru[1d]	Materials Science & Eng	Univ of Pennsylvania	Penn

1. Six (6) students were funded partially or in full by core partner university resources indicated here: 1a=UC Merced, 1b=Purdue, 1c=Penn (NSF NNCI), 1d=Penn
2. Key for Home Institutions: **Bold** = non-R1 or R2 Institution and/or Minority Serving Institutions (MSI); MSI types: **HSI** = Hispanic Serving Institution, **AANAPISI** = Asian American and Native American Pacific Islander-Serving Institutions; **CC** = 2-year community college or Associate's Degree Dominant (MSI Types from the NASA 2023-2024 List of MSIs (Minority Serving Institutions Exchange (nasa.gov))

Appendix Table 4E.2. Placements of IoT4Ag REU Alums (cohorts 2021-2023), who have since completed their degree programs; includes N=3 Associate's Degree REU participants (now all in 4-year programs); * NSF Graduate Research Fellowships Program Awardee

Name	**Current position**	**Current Organization**	**Degree** (Bachelor's unless noted)	**Institution** at time of REU
Caldbeck, Rebecca	PhD Student	Biotech, Univ Cambridge	Ag & Med Biotech; Nat Res & Env. Sci.	Univ of Kentucky
Caldwell, MaTais	PhD Student	Comp Sci, Univ Mississippi	Comp Sci	Auburn Univ
Carrero, Lucia	Electrical Engineer	L3Harris Technologies - Melbourne, FL	Electrical Eng	Univ of South Florida
Christopher Rodriquez	Software Engineer	Northrop Grumman - San Diego	Computer Eng	UC Irvine
Fluker, Edward*	PhD Student	Chem & Biomolecular Eng, Univ Pennsylvania	Chemical Eng	Syracuse Univ
Huang, Brian	Advanced Manufacturing Engineer	Wabash - Lafayette, IN	Mechanical Eng	Purdue Univ
Keskin, Irem	MS Student	Aeronautics & Astronautics, Stanford Univ	Mechanical Eng	Roger Williams Univ
Krueger, Eva	PhD Student	Robotics, Oregon State Univ	General Eng; Env Studies	Swarthmore College

Name	**Current position**	**Current Organization**	**Degree** (Bachelor's unless noted)	**Institution** at time of REU
Lavallee, Breana	Special Asst to Chief Data Officer	NC Dept Environmental Quality	Botany-Plant Bio	North Carolina State Univ at Raleigh
Luna, Nicole	PhD Student	Physics, Univ Colorado	Mechanical Eng	Cal State Polytechnic Univ-Pomona
McCormick, Charles	PhD Student	Chemistry - Polymer/Materials, Univ NC Chapel Hill	Chemistry; Polymer Sci & Eng	Univ of Southern Mississippi
Sripati, Manasa	Research Asst	Bowden Lab, Biomed Eng, Vanderbilt Univ	Bioengineering & Biomed Eng	Univ of Texas at Austin
Striblen, Payton	Undergrad	Elec Eng, Univ Florida	AA, Electrical Eng	Santa Fe College & Univ Florida
Struzyk, Ariel	PhD Student	Chem Eng, California Inst of Tech	Chemical Eng	Cornell Univ
Tindall, Jonathan	Undergrad	Aerospace, Aeronautical & Astronautical/Space Eng, Univ Florida	AA, Engineering	Santa Fe College
Vaughan, Taylor	PhD Student	Organic Chem, Arizona State Univ	Biochemistry	Cal Polytechnic State Univ San Luis Obispo
Veeder, Andie	Asst Chem Engineer	Burns & McDonnell - Kansas City, MO	Chemical Eng	Univ of Arkansas
Vicencio, Kaniel	Undergrad	Comp Sci, Univ Florida	AA, General Studies	Santa Fe College & Univ Florida

Name	**Current position**	**Current Organization**	**Degree** (Bachelor's unless noted)	**Institution** at time of REU
Vyletel, Jackson*	PhD Student	Chem & Biomolecular Eng, Univ Pennsylvania	Chemical Eng	Univ of Notre Dame
Zhang, Jiecheng	MS Student	Aeronautics & Astronautics, Stanford Univ	Aeronautical & Astronautical Eng	Purdue Univ

Appendix Table 4E.3. IoT4Ag RET Participants; Cohort Years span two reporting years (i.e., the program runs June-August); School=school at time of RET

Teacher	**Position** *Teacher unless noted (grades)*	**School** *Philadelphia PA unless noted; HS = high school*	**School Demographics** *CEP=community eligibility provision, % economically disadvantaged*	**RET Cohort**
Buckley, Robert	Math & Science (4^{th})	Alain Locke Elementary	84% Black; 5% Two or more races; 5% Asian; 2% White; 100% CEP	2022
Hassey, Kathleen	Technology (K-4^{th})	Alliance for Progress Charter	95% Black; 3% Two or more races; 2% Hispanic; 100% CEP	2022
Washington, Brandon	Technical Education	Hamilton West HS, Hamilton NJ	38% White: 37% Hispanic; 20% Black; 3% Asian; 45% CEP	2022
Zimny, Richard	Biology	Julia R. Masterman School	41% White; 27% Asian; 16% Black; 9% Two or more races; 7% Hispanic; 38% CEP	2022
Cruz, Eric	Engineering	Kensington HS	56% Hispanic; 29% Black; 8% White; 6% two or more races; 1% Asian; 100% CEP	2023

Teacher	**Position** *Teacher unless noted (grades)*	**School** *Philadelphia PA unless noted; HS = high school*	**School Demographics** *CEP=community eligibility provision, % economically disadvantaged*	**RET Cohort**
Turko, Jacob	Agricultural Program Coordinator	Walter B. Saul HS of Agricultural Sciences	64% Black; 19% White; 13% Hispanic; 3% two or more races; 1% Asian; 100% CEP	2023
Akinyi, Almas	Biology, Environ-mental Science (9-12th)	Lankenau Environmental Science HS	90% Black; 5% Hispanic; 3% two or more races; 2% White; 1% Am Indian/AK Native; 100% CEP	2024
Dunbar, Aszure	Math (9th)	Lankenau Environmental Science HS	90% Black; 5% Hispanic; 3% two or more races; 2% White; 1% Am Indian/AK Native; 100% CEP	2024
Kopp, Alexander	Math & Comp Sci (10th-12th)	Science Leadership Academy at Beeber	76% Black; 10% White; 5% two or more races; 4% Hispanic; 4% Asian; 87% CEP	2024
Ukaegbu, Aloma	Math (7th & 8th)	Science Leadership Academy at Beeber	76% Black; 10% White; 5% two or more races; 4% Hispanic; 4% Asian; 87% CEP	2024

Appendix Table 4E.4. IoT4Ag Student Industry Internships in Y4.

Name	Student Type	Internship Host
Balaji, Aishwarya (Penn)	Undergraduate	Amazon
Carlton, Caroline (Purdue)	Undergraduate	AgReliant Genetics
Carlton, Caroline (Purdue)	Undergraduate	USDA ARS
Crasto, Vernon (UF)	Doctoral	Motif Neurotech Inc.
McCormick, Charles (Univ Southern MI)	Undergrad (IoT4Ag REU)	Oak Ridge National Laboratory
Morales-Ona, Ana Gabriela (Purdue)	Doctoral	Corteva Agriscience (IPAB Member)
Xu, Jun (Penn)	Doctoral	Intel
Xue, Hong (Penn)	Master's	Antora Energy
Zhang, Jingwen (Penn)	Doctoral	John Deere (IPAB Member)

Appendix Table 4E.5. Workshops, Talks, Seminars, Exhibit Booths, and Engagement Meetings provided by IoT4Ag for and with Ag Professionals and Practitioners in Y4.

Title	Type	Descriptions	Date
Introduction to Community Engagement for Technology Adoption: The Example of the Internet of Things for Agriculture Center	Seminars, Colloquia, Invited Talks, etc.	Stofer, K. and Nickerson, C. Workshop to introduce Extension agents and community leaders to community engagement and opportunities associated IoT4Ag; to ideate a model of best practices (multi-way, stakeholder-centered engagement) for community engagement in regard to AI and precision agriculture	8/8/2023
Corn Root Development, Establishment, and High Yield Management	Seminars, Colloquia, Invited Talks, etc.	Quinn, D., 2023. "Corn Root Development, Establishment, and High Yield Management," Maizex Yield Tour, Maizex seeds and Farms.com. Ontario, Canada	8/17/2023

Title	Type	Descriptions	Date
Nitrogen Management of Corn using Precision Technologies	Workshops, Short Courses, and Webinars	Morales-Ona, A. and D. Quinn, 2023. Nitrogen Management of Corn using Precision Technologies. Davis Purdue Ag Center Field Day. Purdue University Ext., Farmland, IN	8/22/2023
Corn Response to Input-Intensive Management. Southeast Purdue Ag Center field Day	Workshops, Short Courses, and Webinars	Quinn, D., and C. Lee. 2023. Corn Response to Input-Intensive Management. Southeast Purdue Ag Center field Day. Purdue Univ. Ext., Butlerville, IN	8/29/2023
Modeling soil temperature with SWAT	Seminars, Colloquia, Invited Talks, etc.	Maghsood, F. Modeling soil temperature with SWAT, a review. Cornell University. September 2023, Ithaca, NY (On-line).	9/1/2023
Corn Starter Fertilizer and Fungicide Management	Workshops, Short Courses, and Webinars	Quinn, D., 2023. Corn Starter Fertilizer and Fungicide Management. At-Plant Meeting hosted by FMC. Tremont, IL	9/8/2023
Community Engagement for Precision Agriculture: Uniting Producers and Researchers for Sustainable Food, Energy, and Water	Workshops, Short Courses, and Webinars	Stofer, K. and Nickerson, C. Virtual webinar, hosted by IoT4Ag and the UF Center for Public Issues Education; To foster community engagement among agricultural growers, communicate mission to create and implement IoT technologies for sustainable agriculture	9/7/2023

Title	Type	Descriptions	Date
Developing a Data-Driven Model for Predicting Water Stress in Pistachio Trees, 15th International Congress on Agricultural Mechanization and Energy in Agriculture	Seminars, Colloquia, Invited Talks, etc.	Developing a Data-Driven Model for Predicting Water Stress in Pistachio Trees, 15th International Congress on Agricultural Mechanization and Energy in Agriculture, Antalya, Turkiye.	10/1/2023
Introduction to the Internet of Things for Precision Agriculture Center – AgrAbility	Seminars, Colloquia, Invited Talks, etc.	Stofer, K.A., Introduction to the Internet of Things for Precision Agriculture Center. AgrAbility monthly meeting. Online.	10/30/2023
Food and Agriculture Festival at Cade Museum	Workshops, Short Courses, and Webinars	Outreach Table with drones, UAVs, sensors, hardware, and real time data collection from physical devices	11/4/2023
IoT4Ag Sensors and Systems for Precision Agriculture @ AIFARMS/UIUC	Seminars, Colloquia, Invited Talks, etc.	C. Kagan, invited seminar, Univ of Illinois at Urbana Champaign, USDA AI Institute AIFARMS	11/14/2023
In-season N Fertilizer Timing and Planter Technologies for Corn Following a Rye Cover Crop - Mid-Atlantic Crops	Seminars, Colloquia, Invited Talks, etc.	Quinn, D., 2023. “In-season N Fertilizer Timing and Planter Technologies for Corn Following a Rye Cover Crop,” Mid-Atlantic Crops Conference. Ocean City, MD	11/15/2023

Title	Type	Descriptions	Date
Integration of Satellite and UAV Imagery for Assessing Corn Nitrogen Uptake at Early Vegetative Growth Stages	Seminars, Colloquia, Invited Talks, etc.	Morales-Ona, A., R. Nielsen, J. Camberato, and D. Quinn, 2023. "Integration of Satellite and UAV Imagery for Assessing Corn Nitrogen Uptake at Early Vegetative Growth Stages," Proceedings Published for North Central Soil Fertility Conference. Des Moines, IA.	11/15/2023
Porters Quarters Community Harvest Festival	Seminars, Colloquia, Invited Talks, etc.	Booth, Local farm festival in conjunction with Santa Fe College Heritage Foods Program and V. Fuentes (EWD-DCI Advisory Board)	11/17/2023
Corn Fertility Management	Workshops, Short Courses, and Webinars	Quinn, D., 2023. Corn Fertility Management. Byron Seeds Corn College. Marshall, IN.	12/5/2023
SW Florida Precision Agriculture Technology Expo	Innovation-focused Workshops, Short Courses, Webinars, and Seminars	UF/IFAS (1st annual) tabling	12/6/2023
Crops and Colors / Grow Hub	Seminars, Colloquia, Invited Talks, etc.	IoT4Ag table for community engagement	12/10/2023
High-yield Corn Management. Pioneer Agronomy Day	Workshops, Short Courses, and Webinars	Quinn, D., 2023. Nitrogen Management of Corn. Co-Alliance Commercial Applicator Training. Indianapolis, IN	12/11/2023
Corn Response to Asymbiotic N-fixing Biologicals. Precision Ag Summit	Workshops, Short Courses, and Webinars	Quinn, D., 2023. Corn Response to Asymbiotic N-fixing Biologicals. Precision Ag Summit. West Lafayette, IN	12/12/2023

Title	Type	Descriptions	Date
Further Understanding Input-Intensive Management of Corn - Purdue	Workshops, Short Courses, and Webinars	Quinn, D., 2024. Further Understanding Input-Intensive Management of Corn. Crop Management Workshop. Purdue University Ext., West Lafayette, IN, Madison Co., IN	1/23/2024
Linking Local Foods and Local Culture Symposium	Seminars, Colloquia, Invited Talks, etc.	IoT4Ag Table	1/23/2024
High Yield and Input-Intensive Corn Management	Workshops, Short Courses, and Webinars	Quinn, D., 2024. High Yield and Input-Intensive Corn Management. 5to Foro Intagri de Maíz de Alto Rendimiento. Intagri. Guadalajara, Mexico	2/1/2024
Peanut leaf spot pathogens and winter field management	Seminars, Colloquia, Invited Talks, etc.	Poster, R. Barocco, "Peanut leaf spot pathogens and winter field management"; Alabama-Florida Peanut Trade Show, Dothan, AL	2/1/2024
75th Annual Corn Improvement Conference	Seminars, Colloquia, Invited Talks, etc.	IoT4Ag members participating in the 75th Annual Corn Improvement Conference, Purdue; Students presented IoT4Ag project posters	2/8/2024
AVENA: Event driven data integration towards informed decisions in cropping sys	Seminars, Colloquia, Invited Talks, etc.	Poster: Pathak, H., Basir, S., Balmos, A., Castiblanco, F. A., Bailey, J. K., Buckmaster, D.R., Krogmeier, J. V., AVENA: Event driven data integration towards informed decisions in cropping system, 75th Annual Corn Improvement Conference, West Lafayette, IN,	2/8/2024
World Ag Expo 2024	Seminars, Colloquia, Invited Talks, etc.	IoT4Ag exhibit booth,Tulare, CA	2/12/2024

Title	Type	Descriptions	Date
Maize Yield Prediction Based on Multi-Modality Remote Sensing and Deep Neural Network Models in Nitrogen Management Practice Trials	Seminars, Colloquia, Invited Talks, etc.	Aviles-Toledo, C., 2024. "Maize Yield Prediction Based on Multi-Modality Remote Sensing and Deep Neural Network Models in Nitrogen Management Practice Trials," Lightning talk and poster at the North American Plant Phenotyping Conference, West Lafayette, IN	2/13/2024
Florida Peanut Federation Annual Membership Meeting & Banquet	Seminars, Colloquia, Invited Talks, etc.	S. Naranjo engaged with consultants and extension agents for row crops in Florida; learned about the beliefs and norms of peanut farmers.	2/24/2024
San Joaquin Valley Gathering & Small Farm Tech Expo - 2024	Seminars, Colloquia, Invited Talks, etc.	IoT4Ag exhibit booth	3/1/2024
Florida Stakeholder Engagement Program (STEP)-Corn Contest-Kickoff Meeting	Seminars, Colloquia, Invited Talks, etc.	Florida Stakeholder Engagement Program (STEP): friendly crop management competitions focused on input use efficiency and profitability; shared experience for growers, industry representatives, policymakers, researchers, and extension agents; goal - to improve crop management and increase the adoption of Agricultural Best Management Practices (BMPs)	3/4/2024
CITRIS_EDGE in Tech Symposium	Innovation-focused Workshops, Short Courses, Webinars, and Seminars	E. Hestir, Panel moderation at CITRIS Innovation on Health, focused on advancing health care for all and job opportunities for technologists and career paths, representing and gender equity in tech fields.	3/8/2024

Title	Type	Descriptions	Date
Watermelon Field Day	Seminars, Colloquia, Invited Talks, etc.	On-farm Extension demonstrations to evaluate the use of controlled-release fertilizers compared to conventional fertilizers in watermelons	4/18/2024
Community Day at the Farm	Seminars, Colloquia, Invited Talks, etc.	Table at rural community event (K. Stofer, S. Naranjo). Live Oak, FL.	4/20/2024
Sustainability Festival	Seminars, Colloquia, Invited Talks, etc.	IoT4Ag table, Alachua County Farmers Market. (V. Crasto)	4/20/2024
Emergence Agriculture: For problems which solutions are obvious in retrospect - Boyce Thompson	Seminars, Colloquia, Invited Talks, etc.	Messina C., Emergence Agriculture: For problems which solutions are obvious in retrospect. Boyce Thompson Institute, Ithaca, NY	5/6/2024
The Corn Silage and Forage Field Day (Citra)	Seminars, Colloquia, Invited Talks, etc.	S. Naranjo met with farmers and extension agents about IoT4Ag program	5/30/2024
Utilizing Molecularly Imprinted Polymers for Aflatoxin Detection - FAME 2024	Seminars, Colloquia, Invited Talks, etc.	Blanch Khouri Sader, Emmanuelle Schue, Taylor Vaughn, Charles McCormick, Brent S. Sumerlin. “Utilizing Molecularly Imprinted Polymers for Aflatoxin Detection” Florida Annual Meeting and Exposition - FAME 2024 (ACS), Palm Harbor, FL, May 2024.	5/30/2024
Corn Field Day	Seminars, Colloquia, Invited Talks, etc.	Talked with farmers and extension agents about the program	6/6/2024

Title	Type	Descriptions	Date
Breeding for Climate Change is imperative but may occur differently as we think	Seminars, Colloquia, Invited Talks, etc.	Messina C, Cooper M. Breeding for Climate Change is imperative but may occur differently as we think. ARC Center of Excellence Plant Success, Brisbane, Australia	6/17/2024
Oaxaqueño/a Farming Practices Demonstration	Seminars, Colloquia, Invited Talks, etc.	Stofer, K., CAFF and Yo'Ville Farm Incubator event; engaged farmers about IoT4Ag, solicited feedback/info re. needs for community farms	6/26/2024
Latino Farmers' Association and Trinity Fruit Company	Innovation-focused Workshops, Short Courses, Webinars, and Seminars	Stofer, K., Tour, meeting with Latino Farmers' Association and Trinity Fruit Company; engagement around IoT4Ag; farmer, grower/packer/shipper needs	6/27/2024

Appendix Table 4E.6. IoT4Ag PhD and Postdoctoral Alumni Placements since 2021 (*occurred during YR4)

Name	IoT4Ag Role	Position after IoT4Ag
Arakawa, Tomohiro	Doctoral	Software Defined Radio Engineer, Lynk
Bliss, Matthew*	Doctoral	Senior Engineer, Raytheon BBN
Chowdhury, Arindam	Doctoral	Algorithm Engineer, KLA
Gholami Pareh, Akram	Doctoral	Robotics Engineer, Promaxo
Iboyi, Joseph*	Postdoctoral	Seed Regulatory Field Research Scientist, Corteva (Pioneer Hi-Bred International) (IPAB Member)
Iyer, Gokulanand*	Doctoral	Head of Product, ReynKo Inc
Johnson, Benjamin V.	Postdoctoral	Mechatronics Engineer, ASML

Name	IoT4Ag Role	Position after IoT4Ag
Malencia , Matthew*	Doctoral	Visiting Researcher, University of Cambridge
Manjanna, Sandeep	Postdoctoral	Founding Faculty, Plaksha University
Mazis, Anastasios	Postdoctoral	Precisions Phenotyping Researcher, Corteva Agriculture (IPAB Member)
Menge, Hayden	Doctoral	Software Development Engineer, Amazon Web Services (AWS)
Miah, Md Abdul Halim	Postdoctoral	TD Module & Integration Yield Engineer, Intel Corporation
Olmedo Pico, Lia	Postdoctoral	Science Fellow, CSIRO (Commonwealth Scientific and Industrial Research Organization), Australia
Rendon-Hernandez, Adrian	Postdoctoral	Senior Electronics Design Engineer, Schneider Electric
Ruiz-Munoz, Jose	Postdoctoral	Assistant Professor, Universidad Nacional de Colombia
Stansly, Theodor	Postdoctoral	Grazing Specialist, National Resource Conservation Service
Suresh, Vinayak	Doctoral	Senior Engineer, Qualcomm
Thayer, Thomas	Doctoral	Robotics Electronics Engineer, SLAC National Accelerator Laboratory
Yu, Guohao	Doctoral	Engineer, Shanghai Micro Electronics
Wang, Taojun	Doctoral	Researcher, Bayer Cropscience LP (IPAB Member)
Zhang, Yaguang*	Postdoctoral	Clinical Assistant Professor, Purdue University
Zhao, Tianshuo	Postdoctoral	Assistant Professor, Hong Kong University

Appendix Table 4E.7. Y4 Center-Wide Seminars

Guest Speaker Seminar				
Date	**Host Institution**	**Speaker**	**Job Title**	**Presentation Title**
12.1.2023	University of Pennsylvania	Jordan Hesterman	Commercial Director, Precision Agriculture | FMC Corporation (IPAB Member)	Advancing Technology in Agriculture: Not a Novelty but a Human Necessity
1.9.2024	Purdue University	Douglas Cook	Associate Professor, Mechanical Engineering	Adventures in Interdisciplinary Engineering: Engineering Superior Crops
1.19.2024	University of Pennsylvania	David Arnold	Innovation Ecosystem Co-Lead	IP and Invention Disclosure Pane
2.2.2024	University of Florida	Christine Angelini	Assistant Professor, Environmental Engineering University of Florida	Florida's Digital Twin: A New Cross-Campus Initiative to Guide Data-Driven Decision Making for a More Resilient Florida
3.1.2024	University of Pennsylvania	Yong Zhu	Yong Zhu, Distinguished Professor, North Carolina State University in the Department of Mechanical and Aerospace Engineering	Soft Wearable Electronics for Plant Health Monitoring
3.15.2024	University of Pennsylvania	Melba Crawford, Reza Ehsani, Dan Quinn, Ian Small	Testbed Leaders (Purdue, Univ. of Florida, Univ. of California, Merced)	Testbed Leaders Panel Q&A and IoT4Ag Database Review
4.5.2024	Purdue University	David Bullock	Professor, University of Illinois Urbana-Champaign	Bullock leads the Data Intensive Farm Management research team
4.18.2024	University of Pennsylvania	David Arnold, Kevin Turner	Innovation Ecosystem and Convergent Research Co-Leads	Revised TRL to ARL / TRL Ratings & Planning for the Renewal

Date	Host Institution	Speaker	Job Title	Presentation Title
5.3.2024	University of California, Merced	Walt Duflock	Senior Vice President, Innovation Western Growers	Specialty Crop AgTech – California challenges, why automation and biologicals are needed, why we need some new capital sources, and what are the big innovation opportunities?
6.24.2024	University of California, Merced	Shely Aronov	Co-Founder and CEO, InnerPlant	Building a Successful AgTech Business Model Beyond Good Technology

Appendix Table 4E.8. Y4 Faculty Engagement in Outreach & Education Events

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
7/5/2023	ACLAMO Camp Workshops 2023	Sue Ann Bidstrup-Allen	University of Pennsylvania
7/9/2023	Optimal application of nitrogen fertilizer in corn for economic returns and environmental sustainability - ASABE AIM 2023	Dennis Buckmaster Charlie Messina	Purdue University
7/10/2023	Active Collaborative Localization in Heterogeneous Robot Teams	Vijay Kumar	University of Pennsylvania
7/12/2023	Delay Tolerant Networking Based on Machine-to-Machine Communications, ASABE AIM 2023	Jim Krogmeier	Purdue University
7/13/2023	S2STEAM and Army Educational Outreach	Vijay Kumar Pratik Chaudhari	University of Pennsylvania

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
8/4/2023	P-AgBot: In-row & Under Canopy Agricultural Robot for Monitoring and Physical Sampling (Experience ACRE)	Dave Cappelleri	Purdue University
8/8/2023	Introduction to Community Engagement for Technology Adoption: The Example of the Internet of Things for Agriculture Center	Katie Stofer	University of Florida
8/16/2023	Visualizing Agricultural Output with Sensors and Digital Twins	Lisa Yeo Charlie Messina	University of California, Merced University of Florida
8/17/2023	Corn Root Development, Establishment, and High Yield Management	Dan Quinn	Purdue University
8/22/2023	Nitrogen Management of Corn using Precision Technologies	Dan Quinn	Purdue University
8/26/2023	UPenn SEAS URM PhD Student Discussion Panel	Paulo Arratia	University of Pennsylvania
8/29/2023	Corn Response to Input-Intensive Management. Southeast Purdue Ag Center field Day	Dan Quinn	Purdue University
9/8/2023	Corn Starter Fertilizer and Fungicide Management	Dan Quinn	Purdue University
9/12/2023	Community Engagement for Precision Agriculture: Uniting Producers and Researchers for Sustainable Food, Energy, and Water	David Arnold Katie Stofer Cherie Kagan	University of Florida University of Pennsylvania

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
9/19/2023	Digital Ag Fest	Dave Cappelleri Dennis Buckmaster Jim Krogrmeier Melba Crawford David Love	Purdue University
9/20/2023	UF Center for Public Issues Education	Cherie Kagan	University of Pennsylvania
9/25/2023	NTCA conference in Boston	Dennis Buckmaster Jim Krogmeier	Purdue University
10/1/2023	Developing a Data-Driven Model for Predicting Water Stress in Pistachio Trees, 15th International Congress on Agricultural Mechanization and Energy in Agriculture	Reza Ehsani	University of California, Merced
10/1/2023	P-AgBot, Workshop on Robotics for Agriculture (IEEE / RSJ) Oct. 2023	Dave Cappelleri	Purdue University
10/1/2023	Robust Localization of Aerial Vehicles via Active Control of Identical Ground Vehicles	Vijay Kumar	University of Pennsylvania
10/5/2023	IoT4Ag Sensors and Systems for Precision Agriculture @ IEEE IROS	Cherie Kagan	University of Pennsylvania
10/9/2023	Ag Adventures	David Arnold Vivek Sharma Ian Small	University of Florida

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
10/11/2023	Whose Stories Get Told? Toward Validation and Representation in Culture and Climate Studies	Ayesha Boyce	Arizona State University (ASU)
10/20/2023	Precision Agriculture: Feeding the World Through Communications and Sensing	David Love	Purdue University
10/29/2023	Corn Yield, Nitrogen Use, and Biological Activity Response to Asymbiotic N-Fixing Bioinoculant Products	Dan Quinn	Purdue University
10/29/2023	Developing Machine Learning-Based In-Season Site-Specific N Recommendations Strategy for Corn Using Satellite Remote Sensing and Multi-Site-Year On-Farm Trial Data	Dan Quinn	Purdue University
10/29/2023	Optimizing irrigation management for sustainable corn production: A simulation study using APSIM	Dennis Buckmaster Charlie Messina	Purdue University
10/30/2023	Introduction to the Internet of Things for Precision Agriculture Center – AgrAbility	Katie Stofer	University of Florida
11/4/2023	Food and Agriculture Festival at Cade Museum	Bill Eisenstadt	University of Florida
11/14/2023	IoT4Ag Sensors and Systems for Precision Agriculture @ AIFARMS/UIUC	Cherie Kagan	University of Pennsylvania

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
11/15/2023	In-season N Fertilizer Timing and Planter Technologies for Corn Following a Rye Cover Crop - Mid-Atlantic Crops	Dan Quinn	Purdue University
11/15/2023	Integration of Satellite and UAV Imagery for Assessing Corn Nitrogen Uptake at Early Vegetative Growth Stages	Dan Quinn	Purdue University
11/17/2023	Porters Quarters Community Harvest Festival	Katie Stofer	University of Florida
11/21/2023	IoT4Ag at Program.it	Cherie Kagan	University of Pennsylvania
11/26/2023	Kevin & Paulo: Brazil Talk (FAPESP Meeting)	Cherie Kagan Kevin Turner Paulo Arratia	University of Pennsylvania
12/5/2023	Corn Fertility Management	Dan Quinn	Purdue University
12/6/2023	SW Florida Precision Agriculture Technology Expo	Katie Stofer	University of Florida
12/10/2023	Autonomous navigation in digital agriculture: Using the segment anything model for corn row identification	Dennis Buckmaster Jim Krogmeier	Purdue University
12/10/2023	Crops and Colors / Grow Hub	Katie Stofer	University of Florida
12/11/2023	Electrodynamic Wireless Power Transfer to High Performance Rotating Magnet Receivers	David Arnold	University of Florida

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
12/11/2023	High-yield Corn Management. Pioneer Agronomy Day	Dan Quinn	Purdue University
12/12/2023	Corn Response to Asymbiotic N-fixing Biologicals. Precision Ag Summit	Dan Quinn	Purdue University
12/15/2023	Outreach Event at Lower Merion High School	Cherie Kagan	University of Pennsylvania
1/23/2024	Further Understanding Input-Intensive Management of Corn - Purdue	Dan Quinn	Purdue University
1/23/2024	Linking Local Foods and Local Culture Symposium	Katie Stofer	University of Florida
1/26/2024	Penn Y-Prize	Kevin Turner Troy Olsson	University of Pennsylvania
2/1/2024	High Yield and Input-Intensive Corn Management	Dan Quinn	Purdue University
2/8/2024	75th Annual Corn Improvement Conference	Dan Quinn Dennis Buckmaster Dave Cappelleri	Purdue University
2/8/2024	AVENA: Event driven data integration towards informed decisions in cropping sys	Dennis Buckmaster Jim Krogmeier	Purdue University
2/12/2024	World Ag Expo 2024	Stefano Carpin Reza Ehsani	University of California, Merced
2/14/2024	Improving Mechanical Shakers for Nut Crops Using an Advanced Data-Driven Model	Reza Ehsani	University of California, Merced

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
2/24/2024	Florida Peanut Federation Annual Membership Meeting & Banquet	Katie Stofer	University of Florida
2/29/2024	IoT4Ag Information Session at Santa Fe - Feb 29, 2024	David Arnold	University of Florida
3/1/2024	San Joaquin Valley Gathering & Small Farm Tech Expo - 2024	Erin Hestir Reza Ehsani	University of California, Merced
3/4/2024	Florida Stakeholder Engagement Program (STEP)-Corn Contest-Kickoff Meeting	Katie Stofer	University of Florida
3/8/2024	CITRIS_EDGE in Tech Symposium	Erin Hestir	University of California, Merced
3/22/2024	Jr. MANRRS Institute March 2024	Katie Stofer	University of Florida
3/22/2024	MANRRS Career Booth 2024	Katie Stofer	University of Florida
4/18/2024	Watermelon Field Day	Katie Stofer	University of Florida
4/20/2024	Community Day at the Farm	Katie Stofer	University of Florida
5/6/2024	Emergence Agriculture: For problems which solutions are obvious in retrospect - Boyce Thompson	Charlie Messina	University of Florida
5/16/2024	Distributed Multi-robot Online Sampling with Budget Constraints	Stefano Carpin	University of California, Merced
5/16/2024	Improving the ROS 2 Navigation Stack with Real-Time Local Costmap Updates for Agricultural Applications	Stefano Carpin	University of California, Merced

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
5/17/2024	Sensors for Detecting Biotic and Abiotic Stress in Plants	Troy Olsson	University of Pennsylvania
5/23/2024	FLY CITRIS with Merced Youth Soccer Association	Erin Hestir	University of California, Merced
5/26/2024	Cost-Effective Microfabricated Silver-Based Paper Cathodes for High-Discharge-Rate Aluminum-Air Batteries	Sue Ann Bidstrup-Allen Mark Allen	University of Pennsylvania
5/26/2024	High-Energy-Density High-Power-Density Micro Aluminum-Air Batteries for Small Scale Quadcopters	Sue Ann Bidstrup-Allen Mark Allen	University of Pennsylvania
5/27/2024	Diversity Panel & Workshop @ GRC	Paulo Arratia	University of Pennsylvania
5/28/2024	FLY CITRIS at Plainsburg Elementary School	Erin Hestir	University of California, Merced
5/30/2024	The Corn Silage and Forage Field Day (Citra)	Katie Stofer	University of Florida
5/30/2024	Utilizing Molecularly Imprinted Polymers for Aflatoxin Detection - FAME 2024	Brent Sumerlin	University of Florida
6/1/2024	Ambient IoT: Communications Enabling Precision Agriculture	Jim Krogmeier	Purdue University
6/2/2024	Extended Flight Duration Small-Scale Quadrotors Powered by High Energy Density, High Power Density, Micro Aluminum Air Batteries	Sue Ann Bidstrup-Allen Mark Allen	University of Pennsylvania

Event Date	Name	IoT4Ag Faculty Participation	Faculty Institution
6/2/2024	Solid-State Sensors, Actuators, and Microsystems Workshop - Hilton Head	Cherie Kagan Kevin Turner Troy Olsson	University of Pennsylvania
6/2/2024	Utilizing Molecularly Imprinted Polymers for Aflatoxin Detection - SMARTS 2024	Brent Sumerlin	University of Florida
6/6/2024	Corn Field Day	Katie Stofer	University of Florida
6/6/2024	NexTech Robotics at the Merced County Fair	Erin Hestir	University of California, Merced
6/9/2024	Plant vascular research and resilient cropping systems	Charlie Messina	University of Florida
6/12/2024	NSF Engineering Research Center (ERC) webinar	Dave Cappelleri	Purdue University
6/13/2024	Smart Cutebot workshop for 4-H students	Dennis Buckmaster	Purdue University
6/17/2024	Breeding for Climate Change is imperative but may occur differently as we think	Charlie Messina	University of Florida
6/17/2024	FLY CITRIS - Bobcat Summer STEM Academy	Erin Hestir	University of California, Merced
6/23/2024	Emergence Engineering in agriculture - Gordon	Charlie Messina	University of Florida
6/26/2024	Oaxaqueño/a Farming Practices Demonstration	Katie Stofer	University of Florida
6/27/2024	Latino Farmers' Association and Trinity Fruit Company	Katie Stofer	University of Florida

Appendix Figure 4E.1. IoT4Ag Bootcamp and Center-wide Annual Retreat Agenda, hosted by UC Merced (63 Bootcamp participants: 47 graduate students and postdoctoral fellows, 12 REU undergraduates, 4 non-REU undergraduates; 102 Annual Retreat participants, including REU, undergraduates, trainees, faculty and advisory board members).

2024 Annual Meeting – UC Merced

IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

For the IoT4Ag retreat, we would like to acknowledge all local indigenous peoples, including the Yokuts and Miwuk, who inhabited this land. We embrace their continued connection to this region and thank them for allowing us to live, work, learn, and collaborate on their traditional homeland. Please take a moment of silence to pay respect to their elders and to all Yokuts and Miwuk people, past and present.

WiFi Access at UC Merced Conference Center
Network: ucm guest **No password**

Student & Postdoctoral Fellow Bootcamp

Sunday, June 23rd

1:00 pm – 3:00 pm **Lunch (Students & Postdoctoral Fellows)**
Only for those with flights arriving earlier on Sunday before hotel check-in time
The Mainzer, 655 W. Main Street

6:00 pm - 9:00 pm **Student & Postdoctoral Fellow BBQ Dinner**
Recommended Attire: Casual
University of California, Merced – Conference Center (5200 North Lake Road, Merced)

Monday, June 24th

7:30 am **Student & Postdoctoral Fellow Breakfast – Tailgate breakfast**
Recommended Attire: Casual
Courtyard Marriott Merced (750 Motel Drive, Merced – parking lot behind the hotel)

8:00 – 11:00 am **Student & Postdoctoral Fellow Morning Tour - Dos Rios Ranch**
Leaving from Courtyard Marriott Merced (parking lot behind the hotel) to depart to Dos Rios Ranch

12:00 – 12:30 pm **Courtyard Marriott Hotel**
Return to the hotel for break

12:30 - 2:00 pm **Student, Postdoc, Industry (IPAB) & Agricultural (ASAB) Mixer Lunch**
Recommended Attire: Casual
University of California, Merced – Conference Center (5200 North Lake Road, Merced)
Room: Ballroom

2024 Annual Meeting – UC Merced

IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

2:00 - 2:30 pm **Student & Postdoctoral Fellow Poster Set Up**

Zoom link: https://upenn.zoom.us/j/99399122656
Password: Bootcamp
Time: 2:30 – 4:45 PM (Pacific) / 5:30 – 7:45 PM (Eastern)

2:30 – 3:15 pm **Student & Postdoctoral Fellow Panel Discussions**
Room: Ballroom
Moderator: Leigh Bernacchi (Executive Director, Valley Inst. for Sustainability, Technology & Agriculture, UC Merced)
Panelists: Trevor Thomas-Uribe (Venture Capital Investor)
Kimberly Gibson (Post-Doctoral Researcher, Valley Inst. for Sustainability, Technology & Agriculture, UC Merced)

3:15 – 3:30 pm **Break**

3:30 – 4:30 pm **REU Student Meeting**
Room: Conference Room 105

3:30 – 4:15 pm **Student & Postdoctoral Fellow Triannual Check-In**
Room: Ballroom

4:15 – 4:45 pm **Data Collection - Students & Postdoctoral Fellows**
Room: Ballroom
Moderator: Mohammed Ibrahim (ASU)

IoT4Ag Faculty Meetings

Zoom Link: https://upenn.zoom.us/j/97275549218
Password: Faculty
Time: 3:30 – 5:00 PM (Pacific) / 6:30 – 8:00 PM (Eastern)

3:30 – 4:30 pm **Renewal Planning**
University of California, Merced – Conference Center (5200 North Lake Road, Merced)
Room: Conference Room 110

4:30 – 5:00 pm **Data Collection**
Moderator: Ayesha Boyce
Room: Conference Room 110

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YR4 Annual Retreat

Monday, June 24th

5:00 pm **Annual Retreat Begins** *(cash bar)*
Recommended Attire: Casual
University of California, Merced – Conference Center (5200 North Lake Road, Merced)

5:00 - 6:00 pm **Student & Postdoctoral Fellow Poster Session**
Room: Ballroom & Lobby

6:00 pm **Dinner Buffet**

Zoom Link: https://upenn.zoom.us/j/95778466524
Password: Welcome
Time: 6:45 – 8:30 PM (Pacific) / 9:45 – 11:30 PM (Eastern)

6:45 pm **Welcome**
Speaker: Chancellor Juan Sánchez Muñoz (UC Merced)

7:00 pm **Retreat Plans**
Speaker: Cherie Kagan (Penn) & Stefano Carpin (UC Merced)

7:15 pm **Keynote Speaker**



Keynote Speaker
Shely Aronov
CEO / Co-Founder
InnerPlant

Shely Aronov is the CEO / Co-founder of InnerPlant, a John Deere-backed company creating crops that communicate via optical signals when they're thirsty or sick to increase yields and reduce chemical use. Born in Israel, she is a Tel Aviv University graduate and holds an MBA from Stanford. Shely is a repeat entrepreneur, having founded a clean-label hummus brand and led a $320M World Bank-funded project to build a wastewater system in Cartagena, Columbia.

Presentation: Good Science and technology are important, but building a successful business is more about business fundamentals, solving a real problem, and developing a minimal-friction solution underpinned by a viable business model. Join InnerPlant CEO and founder, Shely Aronov, as she shares insights from her journey founding a company, guiding it through raising venture capital from investors like John Deere, negotiating development deals with large incumbents like Syngenta, and deploying a product to commercial fields. Shely's keynote will provide audience members with a solid understanding of what an agtech business needs beyond good technology to succeed.

Tuesday, June 25th

6:45 – 7:00 am **El Capitan Shuttle to Breakfast at Courtyard Marriott**

7:00 am **Continental Breakfast – Tailgate breakfast**
Recommended Attire: Casual (bring IoT4Ag T-shirt)
Courtyard Marriott Merced (750 Motel Drive, Merced – parking lot behind the hotel)

8:00 – 10:30 am **Bowles Farm** *(group photo with IoT4Ag shirts)*
Leaving from Courtyard Marriott Merced (parking lot behind the hotel) to depart to Bowles Farm

Zoom Link: https://upenn.zoom.us/j/93326582607
Password: Retreat
Time: 1:00 – 5:30 PM (Pacific) / 4:00 – 8:30 PM (Eastern)

11:30 – 1:00 pm **Lunch & Poster Session 2 (faculty, IPAB, ASAB voting)**
University of California, Merced – Conference Center (5200 North Lake Road, Merced)
Room: Ballroom

1:00 – 1:45 pm **Panel: Joint Ops - Pests**
Room: Ballroom
Moderator: Jim Krogmeier
Panelists: Gene McAvoy (ASAB), Dan Schmoldt (SAB), Andrea Joyce (UC Merced)

1:45 – 2:30 pm **Panel: Joint Ops - Water**
Room: Ballroom
Moderator: Erin Hestir
Panelists: Ryan McKibben (ASAB – Florida Dept. of Agriculture & Consumer Services), Carolyn Cook (California Dept. of Food and Agriculture), Ric Ortega (Grassland Water District); Eduardo Currea (Rivulis); Kevin Assemi (Elevated Ag)

2:30 – 3:15 pm **Breakout Session:**

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1. **Student Career Development**

Zoom Link: https://upenn.zoom.us/j/95629571144
Password: Career

Room: Conference Room 105
Moderator: Kristin Field (Penn)
Panelists: Sarah Kurtz (UC Merced & National Academy of Engineering), Jeremy Groeteke (IPAB – Syngenta), Jordan Hesterman (IPAB – FMC), Barzin Moradi (ASAB – CA Dept. of Agriculture)

2. **Center Sustainability**

Zoom Link: https://upenn.zoom.us/j/96613690857
Password: Sustain

Room: Conference Room 110
Speaker: Pramod Khargonekar (SAB – UC Irvine)

3:15 – 3:30 pm **Break**

3:30 – 4:15 pm **Panel: Stakeholder Engagement**
Room: Ballroom
Moderator: Katie Stofer (Univ. of Florida)
Panelists: Maria Ridoutt-Orozco (Community Alliance with Family Farmers), Jim Ladlee (ASAB – Penn State Ext), Rigo Rios (ASAB - Latino Farmers Alliance / TKE Tierra Consulting)

4:15 – 5:00 pm **Breakout Session:**

1. **Community College Engagement**

Zoom Link: https://upenn.zoom.us/j/92607450579
Password: Community

Room: Conference Room 105
Moderator: Sue Ann Bidstrup-Allen (Penn)
Panelists: Karen Aceves (Ag Tech Workforce Initiative)

2. **Entrepreneurship start-ups**

Zoom Link: https://upenn.zoom.us/j/99518323198
Password: Start-Up

Room: Conference Room 110
Moderator: Steven Weiner
Panelists: Andy Ziolkowski (Cultivian Ventures), York Eggleston (Semantic Labs)

5:00 – 5:15 pm **Evaluation Findings Overview**

2024 Annual Meeting – UC Merced

Moderator: Ayesha Boyce and Mohammed Ibrahim (ASU)
Room: Ballroom

5:15 – 5:45 pm **Perfect Pitch Competition**
Room: Ballroom

5:45 – 6:00 pm **Break / Group Photo**
Room: Lobby

6:00 pm **Board buses to dinners**
6:30 pm *Student & Postdoctoral Fellow Dinner*
Bella Luna (350 Main Street, Merced)
6:30 pm *Faculty, Staff, Advisory Board, Guest Dinner*
510 Bistro (510 W. Main Street, Merced)

Wednesday June 26th

6:45 – 7:00 am **Shuttles from El Capitan and Courtyard Marriot**
Shuttle to breakfast at UC Merced Conference Center
Bring your luggage if you are leaving from UC Merced to the Fresno airport

7:00 – 9:00 am **Continental Breakfast**
Recommended Attire: Casual
Courtyard Marriot Merced (750 Motel Drive, Merced – parking lot behind the hotel)
Room: Ballroom & Lobby

7:30 am **Two Morning Options – Conference Center**

1. **Smart Farm Tour – walking tour**
   Room: Lobby

2. **Book Club: Wisdom of the Last Farmer: Harvesting Legacies from the Land by David Mas Masumoto**

Zoom Link: https://upenn.zoom.us/j/96483590646
Password: Book Club
Room: Conference Room 105
Moderator: Lisa Yeo

8:15 – 8:30 am **Announce Poster and Perfect Pitch Winners**

2024 Annual Meeting – UC Merced

Zoom link: https://upenn.zoom.us/j/94006715819
Password: Retreat
Room: Ballroom

8:30 – 8:45 am	**Evaluation Surveys** **Room:** Ballroom *Moderator: Ayesha Boyce*
9:00 am	**Shuttle Service Begins back to Fresno Airport** **Room:** Lobby

Scientific Advisory Board
SWOT Analysis YR4: July 1, 2023 to June 30, 2024

Strengths

- The Center provides the first, large-scale and integrated (sensing, through to, decision-making) IoT and precision agriculture multidisciplinary research effort in the U.S., and perhaps the world, given the Center's scope and resources.
- The Center has made significant progress. There are clear, focused milestones planned for each Thrust Area. Further, convergent research and its alignment with Center goals is more explicit and demonstrates a deliberate top-down, methodical roadmap for success. By including both field and tree crops, the Center's technologies and systems are likely to be broadly applicable to many agricultural producers and industries.
- The Center has identified three important and impactful research achievements: low-cost, biodegradable soil and leaf sensors and batteries; edge computing and communication for agricultural sensors; and data fusion and melding of biophysical models with sensor and public data. These provide very strong launching pads for increasing scientific, technological, and agriculture impacts of the Center.
- With three land-grant university partners, the strengths of Cooperative Extension and Ag Experiment Stations can be integral to the Center's efforts.
- JointOps is a clever and valuable approach to inform and expand integration across the Center. The addition of a third JointOp in YR4 related to insect and disease management is significant and demonstrates responsiveness to advisory board feedback. This new JointOp also transitions the Center from solely abiotic crop stressors to now include biotic threats.
- A major strength of IoT4Ag is the excellence of participating faculty members. IoT4Ag can also draw on the unique resources of its industry partners. The broader community will recognize the importance of the problems addressed by IoT4Ag and the great potential for benefits from its robust academic-industry partnerships. The WFD efforts (K-12, community colleges, university and professional education) engage all age groups.
- Realizing the limitations of technology readiness level (TRL) staging for agricultural applications, the Center borrowed DoE's adoption readiness level (ARL) concept and has adapted it for IoT4Ag and agricultural applications.

RESPONSE:

We appreciate the recognition of the numerous strengths of our Center, including our pioneering position in large-scale, integrated IoT and precision agriculture research, our significant progress with focused milestones, and our key research achievements in areas such as low-cost biodegradable sensors, edge computing, and data fusion. The excellence of our faculty and the unique resources of our industry partners, combined with our Joint Ops, position us to make substantial impacts in the field. In the coming years, we will continue to leverage the excellent Cooperative Extension and Agricultural Experiment Stations, along with their strong relationships with farmers, to inform the design of our technology and rigorously evaluate IoT4Ag solutions. The robust Innovation Ecosystem we've developed over the Center's first four years, particularly our industry project liaisons, allows IoT4Ag researchers to effectively harness industry expertise.

Weaknesses

- While many projects (but still not all) now include some mention of planned testbed or JointOps activities, those "mentions" are mostly limited to vague "will test" or "will participate" statements. Details are universally scant, i.e., no experimental designs. Full testing details can be left until later, but some mention of test crops, test frequency and duration, measurement metrics, and success targets can be briefly stated in project proposals. It's difficult to achieve project milestones when a definition of successful testing remains unspecified.

RESPONSE:

The IoT4Ag project portfolio includes technologies with TRLs ranging from 1 to 7 and ARLs from 1 to 7. All projects, except for one, reported testbed activity in Year 4. The annual project reports and continuation requests are limited in length and thus do not provide an opportunity to provide full details on experimental plans. However, we will request greater detail on testbed plans in future reports and continuation requests.

Importantly, as we look forward to Years 6-10, deployment and testing of IoT4Ag technologies in Joint Ops will be prioritized within the research plan, and the scope of testbed activities will increase substantially. We will focus each Joint Op largely at a single testbed (Joint Op 1 on nitrogen management will be based at Purdue, Joint Op 2 on water management will be based at UC-Merced, and Joint Op 3 on disease and pest management will be based at the University of Florida). Each Joint Op will be led by the testbed site lead, Quinn, Ehsani, and Small, respectively. On a yearly basis, each Joint Op will establish a detailed test plan and milestones for the current growing season, along with a roadmap for integrating and assessing technologies from individual projects. These Joint Op test plans are expected to address the concern raised above further.

- Ignoring preprints and cross-thrust publications, there exists a dramatic skewing of publication outputs across Thrusts–24, 16, and 5 for Thrusts 1, 2, and 3, respectively. Even allowing that Thrust 3 contains more systems-level integration work, which may take longer to merge all components for full testing, there can still be significant and publishable intermediate advances in the underlying science and technology as R&D progresses. Hence, thrust-level divergence in scholarly contributions is concerning.

When the SAB prepared its SWOT, our publications were not properly listed on the website. We apologize for this error. Many publications are cross-thrust efforts, and this was not reflected in the publication listing. Below is a breakdown of Year 4 publication data (excluding preprints):

Cross-Thrust Publications	
Thrust 1 & 2	5
Thrust 1 & 3	19
Thrust 2 & 3	2

Single-Thrust Publications	
Thrust 1	2
Thrust 2	10
Thrust 3	0

As can be seen from the data above, all thrusts are well represented in the publications. Thrust 1 contributed to 68% of the publications in Year 4, Thrust 2 contributed to 45% of the publications, and Thrust 3 contributed to 53% of the publications.

Some differences in Thrust publications are expected as not all thrusts are the same size (e.g., when measured by the number of faculty, Thrust 1 is the largest and Thrust 2 is the smallest). Furthermore, the type of research varies considerably across thrusts. Many projects in Thrust 3 require the collection

(often over a growing season) and analysis of large data sets. Thus, the time to carry out a single study and prepare a publication can be long. The power and communications projects in Thrust 2 are more likely to generate single-thrust papers at this stage because of the nature of the work. The center publication record grew significantly in Year 4, and, as seen in the data below, there was a large increase in IoT4Ag publications as center research has matured, and we expect this growth trajectory will continue in Years 5-10. Over the next year, we will work with all projects in the Center to understand their publication plans and work with them to overcome barriers if productivity is lower than expected.

	YR1	YR2	YR3	YR4
Peer-reviewed Technical Journals	1	5	3	23
Peer-reviewed Conf. Proceedings	4	2	11	15

Opportunities

- The technologies behind IoT4Ag are advancing rapidly. This presents important opportunities by making projects more flexible to take advantage of these advances. Improving collaborations among excellent faculty members outside the Center could capture important scientific and technical expertise.
- The Seeds of Innovation seminar series, organized by the Center, was a good way to stay abreast of complementary or similar R&D efforts, and demonstrated a notable Center leadership role. The Center is encouraged to continue this effort, and develop new scientific leadership programs, as the Center reaches a more mature stage.
- The team has worked hard and has been successful in building a large set of stakeholders from industry. While there has been some involvement of this built Innovation Ecosystem to enhance/augment Convergent Research, it would be helpful to have a concrete plan for increased research engagement with industry as the Center moves into the next five years.
- JointOps provide for greater research integration in advance of full testbed deployment. At this point in the Center's evolution, three JointOps have been established. However, it is not clear how new JointOps are proposed, evaluated, and established. A clear process for JointOps creation might further encourage creation of new ones that could accelerate project integration and technology deployment.
- Development of an alumni relations effort to stay connected and potentially leverage graduate student and postdoc alumni of the Center may provide an avenue to develop future opportunities and assist in long-term sustainability of the Center.
- Sustainability of the Center beyond NSF funding is now a major goal for the Center leadership. Conceptualization and formulation of an ambitious and achievable long-term vision for the ERC is a great strategic opportunity for the Center.

RESPONSE:

We agree that these points represent significant opportunities for our center and are committed to capitalizing on them. We will leverage the rapid advancements in IoT technologies by maintaining project flexibility and fostering collaborations with external experts and centers. The Seeds of Innovation seminar series will be continued in the coming years, showcasing our leadership in the field while keeping us informed of complementary research efforts. The research team interacts with industry partners through project liaisons, and these interactions have been valuable. We have been working with the IPAB Executive Committee, and the committee leadership has drafted and is now socializing amongst member company's options for an "IoT4Ag Innovation Fund" to invest member dues and sponsor research now and as the Center moves to become self-sustaining beyond the term of the NSF funding. In concert with our project review and proposal cadence, we will review and accept proposals of

new Joint Ops using the mid-Year feedback and end-of-Year project selection process, which allows for guidance from IoT4Ag stakeholders and the identification of new critical issues. At this stage, however, we believe it is more important to focus our efforts on the existing Joint Ops to develop and demonstrate our platform technologies into end-to-end integrated systems rather than spread our resources across additional Joint Ops (see additional details in response to threats below). We expect in ~3 years, with a few growing seasons of technology and system platform development, we will be ready to take on new Joint Ops and shorten the time to system development. We recognize the value of our alumni network and will implement an alumni relations program to support long-term sustainability and create future opportunities. Lastly, we have presented an ambitious yet achievable long-term vision for the ERC and a plan for sustainability beyond NSF funding in the current annual report.

Threats

- While strong and noteworthy progress has been made in YR4, the Center will continue to be challenged merging individual projects with a sharp understanding of the 10-year vision of IoT4Ag and how those research projects, taken together, advance the Center towards achieving its vision. The JointOps approach provides a valuable Center strategy to help achieve its vision. Nevertheless, the mix of merged individual projects and JointOps, alongside integrated and system-level projects (of greater scope and complexity) may be difficult to balance.

RESPONSE:

We recognize this threat and have considered it as we have developed a plan for Years 6-10 of the Center. To ensure we achieve the vision of the Center and demonstrate the impact of IoT4Ag technologies, we will increase our focus on the Joint Ops. The needs of the Joint Ops will be used to inform the scope of projects within the Center. Some existing systems-level projects will be positioned to concentrate most of their effort on a single joint operation. These projects and the testbed leads (i.e. 1: Quinn, 2: Ehsani, 3: Small) will lead the coordination of the Joint Op activities and the integration of data streams from multiple IoT4Ag technologies (see **Figs. 4D.3-4D.5** in the Convergent Research Section of the report for revised Joint OP configurations). By focusing on the Joint Ops and having some project research teams primarily focused within a single Joint Op, with a mandate to help lead the integration of IoT4Ag technologies, the Center will be positioned for success and impact.

- The three current JointOps (water, nitrogen, pests) are certainly critical for many crops. However, going forward, those three foci may constrain IoT efforts toward certain avenues of application and consequently limit the Center's engineering research portfolio.

RESPONSE:

We understand this concern but believe that, given finite resources, it is important to focus on a few Joint Ops over the next few years to realize integrated systems of sufficient complexity that will demonstrate the impact of the Center. The three current Joint Ops focus on critically important problems in agriculture (nitrogen use, water use, disease and pest management) that require new solutions to mitigate environmental impact and ensure adequate production of agricultural practices. Each of the problems is challenging and can only be addressed through the development of new engineered systems that integrate multiple technologies. Demonstrations of IoT4Ag technologies in these Joint Ops will establish confidence in IoT4Ag solutions and ultimately drive and allow for faster development of solutions for additional use cases.
Having noted the above, we will remain open to adding or modifying Joint Ops, as resources allow, in the future based on stakeholder input. We will solicit proposals for new or modified Joint Ops with the

project review cycle on an annual basis to ensure they are appropriately focused and identify important problems not covered in the current Joint Ops. We expect that some of the current Joint Ops may be successful and conclude in years 7 and 8. When this occurs, and resources become available, new Joint Ops will be launched. We will also explore collaborations (e.g., with industry partners) to launch additional Joint Ops that cannot be supported with core Center funding alone.

- Adequately capturing the needs, concerns, and technology adoption landscape for growers of all sizes will continue to be a challenge. While several Center efforts are underway to address adoption generally, technology adoption by small- and medium-sized farms may require special focus at some point along the TRL/ARL maturation spectrum.

RESPONSE:

This is an excellent point, and ongoing projects (Projects 28 and 34) include engagement with stakeholders and adoption studies that engage multiple groups, including interest holders from marginalized populations and small- and medium-sized farms. We also have representatives on our ASAB that are from or work with small- and medium-sized farms (e.g., growers and agricultural agents). We fully understand that the value proposition of the technology is different for farms of different sizes and that systems and interfaces will need to be different across the range of end users.

- While considerable Center progress has been made through individual project mergers and through JointOps, the main threat to IoT4Ag remains the connectivity among projects and ramping up to projects of demonstrable scale. This is crucial for achieving the 10-year Center-level vision.

RESPONSE:

We agree. As mentioned above and outlined in the Year 4 report, the Joint Ops are at the center of the research plan for Years 6-10. A number of existing research projects (e.g. 20_Corn Mass N2, 32_Spray Sys) will be primarily focused within a single Joint Op. These projects and the testbed leads will play a key coordinating role in their respective Joint Ops. Other projects (e.g., sensors, robotics, power, and communication technology) will be used in multiple Joint Ops, and the scopes of these projects will be driven by the needs of the Joint Op. We believe this enhanced focus on the Joint Ops is key to achieving the 10-year IoT4Ag vision.

- Projects appear very focused on (targeted for) particular use cases, which makes sense for R&D purposes at lower TRLs. However, as these projects transition to testbed and JointOp deployment, limiting testing to a single testbed (or JointOp) could hinder generalizability and restrict broader interest by potential industry partners.

RESPONSE:

The Center has a research portfolio that includes fundamental research on sensors, robotics, communication, power, and algorithms that have broad applications even though they are motivated by IoT4Ag-specific use cases. Many of these technologies will be deployed in multiple Joint Ops, and thus, we will have an opportunity to demonstrate their generalizability. As a Center, the power of the core partner universities and our stakeholders is the diversity of crops and agricultural environments in our regions and testbeds, allowing us to transfer our technologies and systems between testbeds for the same crop/Joint Op and for different crops and Joint Ops.

Industrial Practitioners & Agricultural Systems
Advisory Board
SWOT Analysis YR4: July 1, 2023 to June 30, 2024

Strengths

- There is a lot of strong collaborative work happening between many institutions.
- Brings new perspectives to agricultural problems
- The fusion of implementors and solution facilitators through the looking glass of research institutions creates a value multiplier. This multiplier cannot be realized through the typical build/sell model found in the commercial agricultural industry. Research institution staff are uniquely suited to act as mechanisms of multidirectional translation between the science of large-scale agricultural environments and technology development supporting enhanced application outcomes.
- The structure of the IoT4Ag consortium creates opportunities for researchers and sensor developers to pursue technology development within guided parameters and by utilizing available resources. The feedback from private organizations through licensing rights and direct commentary serve as market feedback much earlier in the development process.
- The faculty, staff, and students from the participating university collectively possess a diverse range of talents and experiences necessary for developing the next generation of sensors. Additionally, the IPAB/ASAB members contribute their unique set of expertise, further enhancing the capabilities of this group.
- IPAB member's motivation for participation and involvement should help directly drive effective and accessible products and services.

RESPONSE:
IoT4Ag leadership greatly appreciates recognition of these strengths by our advisory board members. We will strive to leverage them as we continue the Center's work.

Weaknesses

- Some very interesting projects, but not all of them seem integrated into an overall, coordinated effort.

RESPONSE:
Thank you for this feedback. IoT4Ag envisions integration of our research work on two levels. First, our multi-thrust vision of agricultural data sensing, data collection, and actionable recommendations powered by analysis of the collected data defines a well integrated, high-level strategy for addressing the challenge of optimizing agriculture. Second, through Joint Ops, we have already demonstrated how some of the research results from our multiple different thrusts can be integrated and deployed as working solutions in our testbeds. We will continue to illustrate and demonstrate this for additional research results as our efforts continue. But that said, some of our research projects may aim to contribute by advancing our technological field in important ways without necessarily focusing on near-term integration with other IoT4Ag technology.

- There is a sizable number of educated farmers with college degrees who are much more interested and open to trying new ways of doing things, but we are not leveraging the benefit of better connection with them.
- The disconnect between agricultural professionals and the opportunities to leverage their advanced and advancing knowledge and skills is palatable. This, in part, appears to derive from long-term experiences with equipment/solution firms. Firms that in practice, if not in purpose, rely on vicariously increasing levels of authority to hedge uncertainty rather than cultivation of relationships engendering intrinsic motivation and a collaborative spirit leading to greater mutual resiliency and adaptivity.

RESPONSE:
Thank you for these two points of feedback regarding connection with growers. Productive connection with agricultural professionals is a very important objective for our Center. We have adopted a number of measures to facilitate connections with grower stakeholders, including: establishment of our Ag Systems Advisory Board (ASAB) as an active voice for growers, including grower agents, collectives and associations as the primary board members; events and activities at the Extension campuses and facilities of our core institutions; on-site visits and conversations with growers as part of each IoT4Ag annual meeting. We will continue to seek ways to solicit the growers' perspective and incorporate it into our research planning and strategy.

In addition, integrating grower voices and ensuring support for adoption is the focus of the new social science testbed / Adoption Readiness Level work in Project 28_TECH ADOPTION and the new grower office hours for feedback on technologies in development at part of Project 34_ENGAGEMENT.

- If the primary goal of this consortium is to rapidly advance technology towards commercialization, then one of the key elements required in that process is capital. However, NSF funding is not infinite, there is no requirement for funds received to be earmarked for business establishment tasks, and there does not currently exist a structure to allow IPAB members to cast a vote with their dollars as to which ideas they deem as having the strongest merit. Sure, IPAB members have early rights to license technology, but not all technology is ready to license directly from IoT4Ag and in almost every instance, there is no business structure ready to support this technology.

RESPONSE:
Thank you for this feedback. We agree that planning for alternative sources of capital is important to supplement and to support the Center when NSF funding concludes. Indeed, sustainability planning is mandated by the NSF for all ERC's. Toward that end, IoT4Ag leadership has now drafted a comprehensive Self-Sufficiency Business Plan, included in our annual report to NSF. One element of that plan under discussion is an "IoT4Ag Innovation Fund" recently proposed by members of our IPAB, as a vehicle to raise and manage investment capital in support of commercially promising technology developed by our Center and to develop business strategies for translation.

- Academic projects don't always appear to be accompanied by an effort to assess viability for actual implementation, so that practicality of some projects isn't always considered.

RESPONSE:
Thank you for this feedback. We are always welcome and look to the IPAB/ASAB as partners to guide the viability and implementation of our projects and to advance their readiness. We developed and implemented several measures during the past year to more closely couple IoT4Ag research projects with implementation and deployment by users. One such measure is our adoption of an ARL ("adoption readiness level") scale by which all research projects are assessed and scored. Details of the ARL are discussed elsewhere in our annual report. In addition, one of our students, in a summer internship project, developed an ROI analysis framework for use in evaluating the business potential of IoT4Ag sensor technologies, including the performance metrics that need to be achieved to establish sound value propositions.

Opportunities

- Clearly this overall project is making new technologies available to solve agricultural problems. Be sure to continue presenting our agricultural challenges to the technology experts.
- Potential for mentorship and coaching of new scientists to be more effective at what they do, especially in the areas of communication, people connection, and soft skills.
- A new agricultural business model that focuses on broad spectrum collaboration that can eclipse current industry innovation and financial projections.
- Develop solution complete ecosystem so that growers/farmers have easy access to complete solutions and systems enabled by new components developed by IoT4Ag participants…and participants developing these components of a solution have a system to work within to drive the development of this complete solution ecosystem.
- There is an opportunity to use IPAB annual dues as well as additional capital IPAB members may want to contribute to more quickly advance promising technology ahead of others. Additionally, a portion of these merit-based funds should be allocated for business development efforts such as strategic planning, market analysis, customer discovery, early staffing, and technology optimization. Certain private companies within the IPAB are well suited to perform these types of tasks necessary to either better prepare a technology for licensing or begin to build a foundation necessary for the idea to become a self-sufficient business.

RESPONSE:
Thank you for highlighting these significant opportunities. We will consider them all in our planning for this coming year. For example:

- We will aim to utilize our ASAB membership as a source for framing appropriate agricultural challenges for our researchers to tackle.

- An "IoT4Ag Innovation Fund" was recently proposed by several IPAB members which would provide new mechanisms for investing membership dues, and possibly additional capital contributions, in support of commercially promising IoT4Ag technologies,

specifically including business development support. This proposal is now under active discussion.

Threats

- Need a mechanism to make sure that all of the promising approaches have a continuation plan after federal funding expires.

- Sustainability of the movement/innovations into future, especially after the funding runs out.

RESPONSE:
Thank you for these two points of feedback. We agree that planning for alternative sources of capital, to supplement and ultimately replace NSF funding, is important. Indeed, sustainability planning is mandated by the NSF for all ERC's. Toward that end, IoT4Ag leadership has now drafted a comprehensive Self-Sufficiency Business Plan, included in our annual report to NSF. One element of that plan under discussion is an "IoT4Ag Innovation Fund" recently proposed by members of our IPAB, as a vehicle to raise and manage investment capital in support of the most commercially promising technology developed by our Center.

- Constant need to interact and involve boots on the ground and Ag practitioners to ensure the field perspective and avoid developing things in a vacuum

RESPONSE:
Please see our response above to Weaknesses #2 & 3, regarding the importance of a productive connection with the grower community and measures we have implemented to facilitate with those stakeholders.

- The market currently has a sufficient supply of sensors and sensory data available. However, what is lacking is a platform or solution capable of converting this data into meaningful insights for growers. As we work towards developing a hardware solution, Thrust 3: "Agricultural Response System" should concentrate on data interoperability and outcome-based offerings derived from these sensory systems and platforms; we are yet to see demonstrated effort in that direction.

RESPONSE:
Interoperability is often discussed solely regarding technical/functional aspects. But it can be split into foundation, structural, semantic, and organizational levels. Foundational progress certainly stems from all of Thrust 1 connectivity efforts. Recent progress in Thrusts 2 and 3 7_EDGE COMP-COMM and 27_DATA INTEGRATION helps in the structural and semantic aspects with the move toward streaming data so that this data can have value via subscriptions or on-demand requests. Thrust 2 will need to keep semantics under consideration as new sensors are developed and deployed. Project 27 is being renamed INTEGRATIVE INTELLIGENCE as we will be incorporating generative AI into the analytics of unified data streams; this we believe can quickly move the dial on structural and semantic realms. The organizational interoperability (social dimensions of governance, policy, legal, etc.) are factors considered in 28_TECH

ADOPTION.

- An industry entrenched in centuries old traditions and practices that is unlikely or perhaps more acutely unable to invite the dramatic shifts in culture that are necessary to cultivate the reimagining required for a sustained metamorphosis.

RESPONSE:
This is another reason why a productive connection with the grower community is critical for our ultimate success. Please see our response above to Weaknesses #2 & 3, regarding some of the measures we have implemented to facilitate strong connections with our grower stakeholders.

- The center faces a lack of clarity concerning the commercialization roadmap for technologies that have reached advanced TRL/ARLs. To address this, the center should formulate a comprehensive 3-5 year strategic plan aimed at achieving self-sustainability through revenue generation from these "pre-commercial" offerings. This plan should provide a well-defined pathway for transitioning mature technologies to the market, ensuring the center's long-term financial viability and self-sufficiency.

- Uncertainty around IoT4Ag's strategic plan to become self-sufficient. Historic framework would dictate licensing fees and royalties as revenue pathways for the organization, but if we don't increase this frequency through better prepared technologies or stronger business foundations, then this is not a viable option. Further, it is not uncommon, at the time of licensing agreement negotiation, for universities to sum the total NSF-backed funding a technology has received to date as an initial fee required to "pay-back" the university for developing the technology. This is an immediate barrier to early adoption and not an easy hurdle for licensees to overcome right out of the gate. Alternative pathways for IoT4Ag to become self-sufficient must be explored.

RESPONSE:
Thank you for these two points of feedback regarding self-sufficiency. We agree that planning for self-sufficiency, including alternative sources of capital to ultimately replace NSF funding, is important. Indeed, sustainability planning is mandated by the NSF for all ERC's. Toward that end, IoT4Ag leadership has now drafted a comprehensive Self-Sufficiency Business Plan, included in our annual report to NSF. One outside-the-box element of that plan (among others) under discussion is a creative "IoT4Ag Innovation Fund" recently proposed by members of our IPAB, as a vehicle to raise and manage investment capital in support of the most commercially promising technology developed by our Center.

Engineering Workforce Development and Diversity & Culture of Inclusion Advisory Board
SWOT Analysis YR4: July 1, 2023 to June 30, 2024

Strengths

- The Advisory Board met and noted that in the last year, tremendous improvements were made. The team has taken advice previously provided by the advisory board and has begun to implement it. There have been staffing additions that took place which have been impactful to the center. The addition of Kristin Field is a plus. She has the right background. Her experiences are a strength. Adding Ayesha Boyce is a great addition. The utilization of her expertise is a great benefit for the center. WFD and DCI have been well integrated. Their programs that have been established can be made to be sustainable with the partnerships (MSIs//HBCUs).

RESPONSE:

We appreciate and thank the advisory board for their guidance and are very encouraged that it is supportive of our efforts to integrate DCI-EWD. We too have been excited about working with A. Boyce and her team. We have been working with the ASU team to best use their assessments of IoT4Ag DCI-EWD programming to help shape the programming for impact and sustainability.

Weaknesses

- There is an opportunity for communication to be improved overall. The programs need to be clearly articulated with regard to their strategy. The team should continue to leverage expertise with others at their universities. Relate activities to the strategic plan. Find out what is being done well and strengthen that instead of doing too much - there is much benefit in making the activities clearer.

RESPONSE:

Thank you for these observations.

A) We agree. We are reworking our graphic (from the Venn Diagram) to better convey the integration of the NSF Gen-4 ERC Foundational Components and how the specific DCI-EWD activities work together in the strategic plan to deliver IoT4Ag's desired outcomes. In the last two Advisory Board meetings, we shared different iterations for communicating DCI-EWD coordinated themes: i) Teach & Excite - Tech Meets Ag (e.g., K-12 outreach), ii) Education for an Inclusive World (e.g., REU, Pathway to PhD Program), and iii) Enabling Professional Advancement (e.g., MSI-HBCU Scholars Residency, Ag Practitioner Partnerships). We also want to clearly identify programs that set IoT4Ag apart by highlighting those that we consider our "Signature Initiatives." It will be important to communicate at which developmental stage these programs are, as some require efforts for scaling and sustainability, while others are in exploratory stages and require generating more background information and creating test environments. Regardless of program stage, we would like the themes and signature initiatives to guide our allocation to specific programs at each IoT4Ag site so that the Center-wide activities synergize and are aligned with our strategic plan. IoT4Ag leadership is working on a Business and Sustainability Plan for our programs.

B) We agree that there is a pool of expert resources at all the IoT4Ag universities, as well as in their

local communities. At the IoT4Ag Annual Retreat at UC Merced, K. Field had conversations with CITRIS UC Merced Director (E. Hestir) and the Executive Director of Valley Institute for

Sustainability, Technology & Agriculture (L. Bernacchi) about opportunities to create synergy among aligned IoT4Ag, CITRIS, and VISTA programs for the benefit of the youth audiences we serve and for greater impact of all of our missions. L. Yeo (UC Merced faculty) continues to build these partnerships and the local IoT4Ag-UC Merced funding/admin mechanisms for implementation. At UF, K. Stofer was accepted into the NSF INCLUDES Program, Engineering PLUS stEm PEER Academy in April 2024, which is a 2-year program. Stofer is enthusiastic about bringing best practices from this program to IoT4Ag's activities. At Penn, we have had several discussions with our Penn Engineering Online Office about scaling our Pathway to PhD Program, which we are in process of assessing whether a Coursera-format could work. We are exploring ideas for educational activities around weather stations and sensors with the School District of Philadelphia, the Fairmont Water Works, Penn Farm, Netter Center for Community Partnerships and individual schools. At Purdue, we are setting up ways to enable more active coordination of Purdue's outreach activities with Penn and other sites (a former postdoc, now early career faculty member is eager to represent Purdue in our DCI-EWD efforts). Purdue is also deploying its new Solar-Powered Remote IoT4Ag Network Gateway (SPRING) devices across all four IoT4Ag campuses that will route sensor data to a common server that can be accessed Center-wide. For DCI-EWD, we are starting to explore the potential use of SPRING for educational and outreach activities. We will continue to develop and strengthen these relationships and build new ones as appropriate.

C) We appreciate the Board's advice to focus on quality over quantity.

Opportunities

- Cultivate junior faculty to learn about strategies and become more engaged to build the future leadership. Stronger mentorship of junior faculty and postdocs to make a future generational shift. Engagement of two year colleges (Sante Fe Community College) - they can replicate the programs they have established and recruit those students for participation in the REU. Start conversations with Industry and get them to be more engaged for example through co-sponsorships of students to ensure future sustainability (when ERC funding is gone). The overall field is attractive to URMs and the team should make a strong effort of aligning their recruitment efforts with the shifting dynamics. There is an opportunity to strengthen engagement with board members and to perhaps create a dashboard that connects goals to strategies to outcomes. This may be a good way to keep the board members updated of what the outcomes are. There is an opportunity to accelerate the work and make it more refined (and get regular feedback from board members).

RESPONSE:

Thank you for identifying these areas for strengthening our portfolio and the suggested mechanisms of how the work of IoT4Ag can live on beyond the Center's lifespan.

A) We have 10 IoT4Ag postdocs and seven junior faculty at our four IoT4Ag campuses over this reporting period (July 2023-June 2024). One postdoc is involved with leadership in the Student & Postdoc Leadership Council (K. Dilmurat at UC Merced), two of these faculty are involved with DCI-EWD leadership (K. Stofer at UF, L. Yeo at UC Merced), and one faculty member recently joined the IoT4Ag Convergence Team/Executive Committee (P. Chaudhari at Penn). We will invite our

postdocs and pre-tenured faculty to respond to a survey at the start of the Fall 2024 semester that asks them specifically about additional mentorship or programming from IoT4Ag in which they might be interested in participating. More generally, we would aim to get insight about perceived gaps in mentorship that IoT4Ag could offer to complement available mentorship/resources they are receiving from other institutional sources (e.g. for Penn postdocs (N=6 of 10), the university-wide Office of Postdoctoral Affairs provides many resources). We are sensitive to the fact that folks in these career stages often already feel like they are balancing too many demands, with too little time for activities that they feel will count for career advancement.

B) We were pleased to support three students from community colleges (CC) in our 2024 REU program (one from Santa Fe College doing research at Purdue and two from Merced College, who were placed at UC Merced). We are encouraging these students to return assessment surveys to the ASU evaluation team and will also reach out to their host labs to get additional feedback about these students' and their mentors' experiences. Feedback will be especially important to make sure we are providing the type of programming that works as well for CC students as for four-year degree program students; or we need to consider whether different CC programming would provide better alignment with our strategic plan and capacities. We also will seek input from V. Fuentes and other Board members with CC expertise.

C) We agree that our current environment in which many young people are called to action by climate-related challenges, including food, energy, and water security, makes STEM and agriculture an exciting space for impact. Students, especially first-gen and/or from low-socioeconomic status families, often are drawn to careers that enable them to be part of the solutions for societal problems. One of our RET middle school teacher's final presentations stressed that one of her IoT4Ag take-homes was related to the (new to her) projection of global population growth by 2050 and the need for action now for sustainable food production. Time with middle school campers from a Latino community organization is very short, but we did introduce IoT4Ag's mission, in our brief slide presentation (also translated into Spanish by a graduate student volunteer) to the 35 kids when they were on Penn's campus to participate in the hands-on demos. At the IoT4Ag Annual Retreat in Merced in June 2024, REU undergraduate and graduate students and postdocs participated in field trip tours of Dos Rios Ranch and Bowles Farm, where topics spanning environmental science, agriculture, technology and social science around food production and workers brought to life the potential impact on society related to their IoT4Ag-affiliated training. It is a priority for us to continue to accelerate our contributions to broadening participation in STEM and agriculture.

D) We are very appreciative of our Advisory Board's deep expertise, and enthusiasm about being called upon for additional service around members' areas of expertise. We have started to work with D. Uueda in the K-12 space. Now that 2024 summer programming has ended, there will be IoT4Ag staff capacity to do this for other areas in preparation for the upcoming year and for the second half of the Center's plan and programs. A dashboard is a great idea.

Threats

- What is being done to retain the talent that is currently on their team particularly the staff. What is being done to retain the faculty, especially URMs. What is the strategy so people can feel supported through the challenges ongoing in Higher Education as well as the political arena. Given the national difficulties in recruiting talented and diverse teams - if they want to maintain URMs, there will need to be better and more targeted recruiting strategies.

RESPONSE:

We appreciate the Advisory Board keeping these ongoing, hard, and tenacious problems at the forefront. Over the summer, K. Field has been participating in the inter-ERC DCI-leads' monthly Zoom meetings, where there have been ongoing conversations about the current political national/regional contexts and best practices. The upcoming Biennial ERC meeting (Alexandria, VA, Sept. 8-10, 2024) will provide another opportunity for NSF and inter-ERC conversations and planning. K. Field, at the request of the Inter-ERC Student and Postdoc Leadership Council's President (A. Hampton), will co-lead a session with Hampton on Sept.10 on the topic of supporting ERC students and postdocs.

Talent recruitment and retention at staff and faculty levels require a deep integration with and support from institutional policies, actual practices and resources, as well as from funding sources. We value our Advisory Board's support of examining ways to strengthen recruitment and retention resources, and ultimately, practices.

Student and Postdoc Leadership Council
SWOT Analysis YR4: July 1, 2023 to June 30, 2024

The IoT4Ag SWOT survey was answered by students and postdoctoral fellows from the University of Florida, University of Pennsylvania, University of California Merced, and Purdue University. The key strengths, weaknesses, opportunities, and threats are highlighted below.

Strengths

- Interconnectedness and Interdisciplinary Collaboration
  - Strong collaboration between universities and research groups is highlighted by ~60% of the survey respondents.

- Innovation and Practical Application
  - 40% of the survey respondents highlighted that the center focuses on real-world problems and tries to find practical research solutions.

- Resources and Support
  - 50% of the respondents highlighted that the Center provides great support towards their learning by providing necessary equipment and financial support, including ITEX supports, which allows them to travel to other partnering students.

- Leadership and Community
  - Strong leadership and mentoring programs are highly valued both in the research groups and at center-wide levels.

RESPONSE:

Thank you so much for identifying and sharing your feedback on key strengths of the Center.

Weaknesses

- Communication and Coordination Challenge
  - 50% of the respondents mentioned that due to geographic constraints, it is hard to communicate and coordinate easily and hence sometimes collaboration fails.

RESPONSE:

Communication across partner institution campuses can be challenging. We are working to gain greater acceptance on the use of Slack to enhance communication and coordination and to ease the burden of the geographic constraints. As we discussed, we have now brought an SPLC channel into the IoT4Ag working group. We look forward to working with SPLC leadership to determine if it meets our expectations and avenues to improve communication. In addition, we strongly encourage students and postdoctoral fellows to request ITEX funds to support in-person collaboration efforts. The intent of the ITEX funds is to increase collaboration and coordination.

- Student and Faculty Engagement and Involvements
  - 40% of the respondents highlighted that there is a lack of driving forces from faculty to encourage student participation due to which there is a very low involvement of students beyond their research projects.

RESPONSE:

We strongly encourage and invite all students and postdoctoral fellows to participate in Center activities beyond just research projects. These activities include participating in the Triannual Student & Fellow Check-Ins, serving as a mentor in the Pathways to Ph.D. Program, mentoring an REU student, volunteering at K-12 education and outreach events, staffing an IoT4Ag exhibit booth at conferences, attending and participating in the Annual Retreat and Center-wide meetings, joining the student Boot Camp prior to the Annual Retreat, participating in student & fellow social events held at each partner institutions, and participating in career building / climate activities. We are very interested in working with the SPLC to continue identifying other programs of interest to students and fellows. We will work with faculty across the Center to express the benefits and encouragement of student & fellow participation.

- Interinstitutional Collaboration and Data Sharing
  - 30% of respondents mentioned that data sharing hinders the collaboration
  - Respondents also addressed that industry partners show very little interest and poorly communicate with students.

RESPONSE:

We will add data sharing difficulties to our next Center-wide meeting for discussion and recommendations.

Thank you for bringing up the concern with industry engagement with students. We and our innovation ecosystem co-leads will discuss this issue discreetly with a few of our industry advisory board members, to get their assessment of the situation and to explore ideas on how to encourage and create opportunities for industry members to more fully engage with the students and fellows, including some of the ideas raised below in the Opportunities section: invited talks, industry site tours, and increased mentorship and internship opportunities.

- Organizational and Structural issues
  - 30% of respondents identified that the long meetings and bureaucratic and segmented structure reduces efficiency.

RESPONSE:

We do aim for meetings to be no longer than an hour, unless the meetings are solely and specifically research as those meetings are most likely driven by work / tasks. We would also like to invite the SPLC to meet with the Center leadership to understand the 2nd point regarding "bureaucratic and segmented structure".

Opportunities

- Enhanced Collaboration and Networking
  - 50% of respondents mentioned that there is a need for enhanced collaboration and networking opportunities, which could be possible by more in-person meetings or at annual retreats.

RESPONSE:

In-person meetings for project collaborations at the Annual Retreat is a fantastic recommendation. While the Annual Retreat is often tightly scheduled, finding opportunities for in-person collaborative meetings could be something that we could add going forward. Again, we hope the use of ITEX funds helps students and fellows plan to meet in-person for research collaborative efforts. We also encourage students and fellows to participate in education and outreach activities that would provide an in-person opportunity to network and to build a community.

- Outreach and Community Engagement
  - The importance of community engagement, such as farmers, extension educators, and younger students, and organizing more outreach activities were highlighted by 40% of the respondents.

RESPONSE:

We couldn't agree more. As mentioned above, we will add this request to our next Center wide-meeting for discussion and to encourage all members to take advantage of participating in outreach and community engagement events.

- Industry Collaboration and Educational Resources
  - 30% of respondents highlighted the need for more industry collaboration, internship opportunities, and technological support.

RESPONSE:

Please see our response above regarding the concern that industry partners do not show enough interest in students.

- Three related questions were asked related to opportunities:

1. What can the center do to assist you in your academic or career progression?
   Following were the responses:
   - Increase in-person interactions to facilitate better communication and engagement
   - Help in obtaining internship and industry collaboration
   - Increase networking and career support
   - Assistance in constructing research paper and publications

RESPONSE:

1. We are open to ideas that the SPLC might have to increase in-person interactions beyond what was mentioned above. 2. We will also more actively post industry internships in our Weekly Monday notice from our IPAB members, and will look for ways to strengthen industry collaborations. 3. We did include a student career panel at last year's Annual Retreat that we hope was helpful. We can continue including student career panels in future Annual Retreats. 4. Finally, we will arrange a presentation on drafting a research paper and publications. This is another great topic for planning the next year's Center-wide presentations.

2. What emerging technologies or fields should the center consider focusing on to stay ahead for the new term?
    - 40% of respondents highlighted that the center should focus on agronomy, plant science, and biotechnology to balance the high number of engineers
    - 50% emphasized to incorporate more AI into communication and large language models
    - 20% highlighted the importance of stakeholder engagement and ethical considerations

RESPONSE:

Thank you for sharing this information!

3. How can the Center better engage with the industry to translate research into practice?
    - 60% of respondents emphasized on making industry interactions more accessible by inviting them for talks and mentorship
    - 50% highlighted by facilitating internships at relevant companies and 30% suggested to organize industry tours

RESPONSE:

Thank you for these recommendations. As we build out next year's Center-wide meetings, we can look to increase the number of IPAB and ASAB members that give seminars and we can explore mentorship opportunities and potential industry tours with industry members. We will continue to work with the IPAB members to identify internship opportunities to post on our Monday Weekly Notice. Please also see our response above regarding the weakness/concern that industry partners do not show enough interest in students.

Threats

- Lack of Student Involvement and Clear Plans:
    - 30% of respondents highlighted the lack of student involvement and clear project plan and meeting purposes.

RESPONSE:

We appreciate the feedback, and plan to use Center-wide meeting times for project planning and meeting purposes.

- Industry and Stakeholders Engagement:
  - 30% of respondents emphasized that the center needs improved industry and stakeholder engagement to translate the current research into technology that could be used by farmers.

RESPONSE:

Productive engagement with our industry partners and other stakeholders is key to making a successful impact through our research, and is a priority for our Center. The Center continues to work to increase participation of industry and the end-use agriculture community in our IPAB and ASAB. IoT4Ag already solicits and receives from IPAB and ASAB members at various points during the year. In Years 5+, the Center will increase its focus on the Joint Ops. This is an excellent opportunity and structure for us to continue our Joint Ops panels and engage industry and farmers in guiding translation.

- Lack of Connectedness
  - 40% of respondents believe that lack of collaboration and interconnectedness is the threat to the center.

RESPONSE:

We moved to focus communication/add channels using the Slack platform for communication across campuses and time zones; ITEX funds are available to encourage in-person student and fellow research collaborations; and the student-led Boot Camp, Center Annual Retreat, and outreach and social are opportunities to connect and network in-person.

We are open to suggestions and recommendations to improve collaboration and interconnectedness!

Although the center had some weaknesses but overall, the center performance was rated **4.1/5 and its activities such as annual retreat (4.4/5), testbed meetings (3.6/5), thrust/center-wide meetings (3.4/5), social events (3.3/5), and workforce development (3.3/5).** However, the SPLC's performance really admired the work done by SPLC members apart from research to the mental well-being of the students by organizing events related to mental health and professional development. **The SPLC overall rating of performance was 3.9/5**, which certainly highlights more area of improvement, such as organizing more in-person events, engaging more people and outreach. Some of the respondents also suggested that SPLC should have regular newsletters, social media updates, and well-planned events that could enhance its impact.

In summary, while the IoT4Ag initiative boasts significant strengths and opportunities, addressing its communication, coordination, and engagement challenges will be key to its continued success. The insights gathered from the survey provide a roadmap for strategic improvements that can enhance the initiative's impact and sustainability.