



Washington State University
Center for Precision & Automated
Agricultural Systems

2016



Center for Precision
&
Automated Agricultural Systems

Our Mission:

“We strive to develop a World preeminent and Washington relevant research and educational program in the areas of agricultural automation and precision farming. Our mission is to provide a venue for:

- ◇ High impact research outcomes for our stakeholders; the specialty crop agricultural community
- ◇ True trans-disciplinary collaboration within WSU and World-wide
- ◇ High quality educational and research experiences for our students
- ◇ Incubation and development of new ideas relevant in an entrepreneurial climate”

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Acknowledgement of Support

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Executive Summary

Qin Zhang, CPAAS Director

The Center for Precision and Automated Agricultural Systems (CPAAS) was designed to offer a framework for agriculture automation efforts at WSU. To create a critical mass of expertise, CPAAS has recruited a diverse group of 15 affiliated faculty from the Department of Biological Systems Engineering, School of Chemical Engineering and Bioengineering, Department of Crop & Soil Sciences, School of Economic Sciences, School of Electrical Engineering and Computer Science, Department of Horticulture, School of Mechanical and Materials Engineering, and WSU Extension, to engage in shared common research interests in agriculture automation and precision agriculture. Multiple brainstorming and team building events were conducted in 2016 to style our philosophical intents into a few strategically well-planned actions to achieve our goals.

Developing mechanization and automation solutions for crop production for Washington agricultural industry and beyond is one of the top CPAAS research priorities as suggested by the CPAAS External Advisory Committee (EAC) and approved by the CPAAS Faculty Executive Committee (FEC) and then the affiliated faculty. Two-thirds of the faculty is actively involved in this area of research. A few representative federal, state and industry funded research projects include the development of mechanical and robotic harvest technologies for fresh market apples, a robotic system for in-orchard fruit bin management, mechanized weed control in vegetable crops, and harvesting technologies for high-yield biomass feedstocks for biofuel. Precision agriculture (PA) and decision support is another research focus area for CPAAS, with about one-half of the faculty actively conducting research and scholarly activities in developing PA related technologies, including in-orchard wireless sensor networks, precision and automated irrigation systems, high throughput phenotyping, sensing, an automated labor management system for fruit harvest, and cloud computing based farming management. More recently, a group of faculty has actively become involved in research and outreach activities on adopting unmanned aerial system (UAS) technologies for agricultural applications. A few pilot projects have been conducted to assess the feasibility and to identify and remove technical obstacles to making UAS practically useful in production agriculture.

In acquiring and leveraging funds to support these

research activities, the Center has put great effort on organizing trans-disciplinary research teams, both within WSU and at a multi-institutional level, to facilitate and/or coordinate the development of many extramural grant proposals, with considerable success. In 2016, CPAAS team had a total research budget of \$4,389,125 for projects proposed and managed through affiliation with CPAAS.

Numerous CPAAS research projects have made an impact on increasing the efficiency and productivity of Washington growers in the past a few years. For example, a few technologies, such as an automated labor management system, a hand-held mechanical blossom thinner, and a high-trellis hop twining robot, have been either commercialized by local manufacturers or adopted by individual growers. In 2016, the group filed 5 more invention disclosures, and was awarded one U.S. patents based on previously filed disclosures. CPAAS faculty has served as the organizer for 2 international professional conferences, been invited to give a total of 31 invited speeches in various international and national events, and 2 faculty members were elected into different leadership positions due to their reputation in corresponding fields.

To continue internationally recognized high impact research and outreach activities, the faculty came to a consensus on a 5-year plan for 2017-2022 in our 2016 retreat which include: 1) to facilitate or coordinate the development of at least five transdisciplinary research proposals each year in hope of bringing in at least \$8 million extramural grants; 2) to edit and publish at least one technical book on the area of agricultural automation and precision agriculture; 3) to organize and host at least one international professional conference; 4) to organize or sponsor one technology expo to our stakeholders to disseminate research outcomes to general public, potential technology adopters, and end user growers; and 5) having 3-5 research prototypes ready for commercialization. An assessment matrix for this 5-year goal has also been developed.

Faculty Productivity



CPAAS Affiliated Faculty



Qin Zhang

Director– Center for Precision & Automated Agricultural Systems

Professor- Biological Systems Engineering

Dr. Qin Zhang is the Director of CPAAS, and a Professor of the Biological Systems Engineering Department. He received his Ph.D. degree from the University of Illinois at Urbana-Champaign in 1991, his M.S. degree from the University of Idaho in 1987, and his B.S. degree from Zhejiang Agricultural University in China in 1982. Prior to his arrival at WSU, Dr.

Zhang was a professor at the University of Illinois at Urbana-Champaign, and before joining the faculty at UIUC in 1997, he worked at Caterpillar Inc. as a Senior Engineer. Dr. Zhang has focused his teaching and research activities on agricultural mechanization, agriculture automation, and agricultural robotics. Based on his research outcomes, he has written 2 textbooks, edited 2 technology books and 3 conference proceedings, published 135 peer reviewed journal articles, presented over 200 papers at different professional conferences, and has been awarded 10 U.S. patents. He currently serves as the Chair for Section III (Plant Production Equipment) of CIGR (International commission of Agricultural and Biological Engineering) and the Editor-in-Chief for *Computers and Electronics in Agriculture*. He is an ASABE Fellow and Club of Bologna Full Member.



David J. Brown
Associate Professor of Soil Science
Department of Crop and Soil Sciences

Dr. Brown and his research group focuses on measuring, modeling and explaining the spatial variability of soil properties and processes at hillslope to regional scales. In pursuing this research, they make extensive use of digital terrain modeling, optical remote sensing, spatial statistics, and proximal soil sensing techniques (e.g. VisNIR spectroscopy).



Paul G. Carter
Associate Professor
WSU Regional Extension Specialist
Soil Science and Precision Farming

Dr. Paul G. Carter joined WSU Extension in 2005 serving the Columbia County Extension Office and a WSU Regional Extension Specialist. In 2011 he joined CPAAS as a remote sensing and dry land precision agriculture specialist working in the SE Washington area. From Purdue University, he earned his B.S. (1974) in Agriculture Mechanization, M.S. (1999) in Agronomy Remote Sensing and Soil Science, and Ph.D. (2005) in Agronomy Remote Sensing. While completing degrees at Purdue University, he worked as a staff member with the Laboratory for the Applications of Remote Sensing (LARS) and the Department of Agronomy. Paul's Extension programs include precision ag technology applications, soil quality, and cropping systems and is currently working with soil acidity, precision lime placement, and nutrient balancing. He participates in many of the county and state agricultural organizations including President of the Washington State Crop Improvement Association. Paul is editor of the Journal of Precision Agriculture and presents at regional, national and international conferences. His leadership has impacted the adoption of precision technologies in the dry land wheat production area of South East Washington State.



Karina Gallardo
Associate Professor/Extension Specialist
Puyallup Research and Extension Center
School of Economic Sciences

Dr. R. Karina Gallardo is an Associate Professor/Extension Specialist in the School of Economic Sciences. She is stationed at the Puyallup Research and Extension Center and is affiliated faculty of the Center for Precision and Automated Agricultural System at Washington State University. She holds a BS in Food Science from Universidad Nacional Agraria La Molina (Lima, Peru), a Master in Science in Agricultural Economics from Mississippi State University and a PhD in Agricultural Economics from Oklahoma State University. Gallardo's primary research and outreach program goal is to enhance value-added agribusiness opportunities for specialty crops in the state of Washington. Her areas of research focus on consumer demand analysis and economics of technological change. Gallardo is conducting research assessing consumers' preferences for fresh fruit quality, and understanding the profitability and various other factors affecting growers' adoption of new technologies, such as new cultivars, improved pest management systems, and labor enhancing mechanisms.



Gwen-Alyn Hoheisel
Area Extension Educator
WSU County Extension Prosser
Executive Board Member, CPAAS

Gwen-Alyn Hoheisel started in 2006 as a faculty member with WSU Extension working in commercial tree fruit and grapes. She received her Master's degree in entomology from Pennsylvania State University in 2002, and her B.S. degree in zoology from University of Maryland in 1998. Hoheisel has focused her work on sustainable pest management, application technologies, and the use of digital media to enhance information delivery to growers. Hoheisel also sits as an ex-officio board member to five Washington tree fruit and grape commodity organizations.



Pete W. Jacoby
Professor – Crop and Soil Sciences
Affiliated CPAAS, Horticulture, Viticulture & Enology
Executive Board Member CPAAS

Dr. Peter Jacoby returned to a faculty position after serving two decades as a College Administrator in Texas, Nebraska, and Washington State. In 2014, he re-engaged in teaching, extension education, and applied research with emphasis on sub-surface micro-irrigation for high value specialty crops, including grapes, hops, and small fruit. His previous areas of research focused on studies of root system dynamics of perennial shrubs and plant eco-physiology. Although located on WSU Pullman campus, Dr. Jacoby's field research program operates from Prosser at the WSU Irrigated Agriculture Research & Extension Center. Professor Jacoby is active in the Irrigation Association, American Society of Agricultural & Biological Engineers, American Society of Enology & Viticulture, and the American Society of Agronomy. He received his M.S. and Ph.D. from the University of Wyoming and his B.S. from Texas A&M University.



Manoj Karkee
Associate Professor
Biological Systems Engineering
Executive Board Member, CPAAS

Dr. Manoj Karkee is an affiliated faculty member to the center and is an associate professor in the Biological Systems Engineering Department. Dr. Karkee was born in Nepal where he received his undergraduate degree in Computer Engineering. He then went to Asian Institute of Technology, Bangkok, Thailand in 2003 for his Master's Degree in Remote Sensing and GIS. He joined Iowa State University in 2003 and received his PhD in Agricultural Engineering and Human Computer Interaction. Dr. Karkee joined WSU in 2010 and has established a strong research program in the area of agricultural automation and robotics with particular emphasis on sensing and control systems including machine vision. Some of his sponsored projects include apple and cherry harvesting, weed control in vegetable crops, fruit tree and berry bush pruning, and solid set canopy delivery. He has published in journals such as 'Journal of Field Robotics', 'Computers and Electronics in Agriculture', and 'The Transactions of ASABE' and has been an invited speaker at several national and international conferences. He is currently serving as the Associate Editor for 'Transactions of the ASABE' and 'Applied Engineering in Agriculture', in the editorial board of 'Image Processing in Agriculture', and in the editor advisory board of 'Computers and Electronics in Agriculture'.



Lav Khot
Assistant Professor
Biological Systems Engineering

Dr. Lav Khot is an affiliate faculty member of the CPAAS and is an assistant professor in the Department of Biological Systems Engineering. He obtained his M.E. from Asian Institute of Technology, Thailand (2004) and M.S. from Iowa State University (2006). He received his Ph.D. from North Dakota State University in 2009. Prior to joining WSU, he was postdoctoral researcher at Citrus Research and Education Center, University of Florida. His research and extension program at WSU focuses on “Sensing and automation technologies for site specific and precision management of production agriculture” with special emphasis towards integration of Proximal and Remote (Unmanned and Manned Aerial Systems) Sensing, Decision Support Systems and Information Delivery Technologies, Precise Applications of various Production Inputs, Agricultural Machinery and Processes, and Data-based Modeling. He is an active member of the American Society of Agricultural and Biological Engineers (ASABE) since 2005 and is an Associate Editor for the PM division of Transactions of ASABE journal.



Karen Lewis
Professor, Regional Tree Fruit Extension Specialist | Tree Fruit Extension Team Leader

Karen Lewis is a WSU Extension Regional Tree Fruit Specialist housed in the Grant-Adams Area Extension office and CPAAS. She earned her B.S. degree in Plant Science and her M.S. degree in Horticulture at the University of Arizona. Karen’s extension and applied research program has been guided by active participation and leadership in international, multi state and statewide academic teams and grower member industry organizations. Current program focus includes: development and integration of mechanized / labor assist technologies for tree fruit pruning, thinning and harvest; competitive apple and pear orchard systems; Engineering, horticultural and economic strategies for sustained production of high quality tree fruit nursery stock and ‘Manchurian’ Crabapple replacement. Lewis has secured over \$2M in program support, jointly published 10 articles in horticultural and engineering journals and has been an invited speaker at conferences throughout the United States and fruit producing regions around the world.



Changki Mo
Associate Professor
School of Mechanical and Materials Engineering

Dr. Changki Mo is an affiliated faculty member to the center and is an associate professor in the School of Mechanical and Materials Engineering at Washington State University-Tri-Cities. He received his Ph.D. degree in Mechanical Engineering from the University of Oklahoma in 1996. Before joining WSU, Dr. Mo was Visiting Professor in the Department of Mechanical Engineering and Materials Science at the University of Pittsburgh, Pittsburgh, PA and Associate Professor in Automotive Engineering Department at Kyungpook National University (Sangju, South Korea). His research interest includes vehicular and structural vibration control, hydraulic control system, energy harvesting: self-powered medical implants and self-powered structural health monitoring, micro actuators and sensors, adaptive structure technology, and smart structures for sustainable buildings. Much of his current research focuses on morphing systems using shape memory polymer and piezoelectric systems for actuators, resonators, sensors, or energy sources. He has published about 50 peer reviewed journal and conference articles and one book chapter.



Stefano Musacchi
Associate Professor; Endowed Chair – Tree Fruit Physiology and Management
Department of Horticulture

Dr. Stefano Musacchi joined WSU as the Endowed Chair of Tree Fruit Physiology and Management at the Department of Horticulture in August of 2013. Musacchi previously worked at the University of Bologna where he earned his doctorate in Pomology in 1996 and was appointed Assistant Professor in 2000. Musacchi's expertise is mainly on apple, pear, and cherry horticulture. He has been involved in pear rootstock evaluation and cultivar breeding and released four new pear cultivars in 2014. Musacchi is the author of over 120 publications in both Italian and English. In addition, he has served on many scientific committees for international meetings and as reviewer of many refereed journal articles.



R. Troy Peters
Extension Irrigation Specialist/Associate Professor
Biological Systems Engineering

Dr. R. Troy Peters works for Washington State University and serves as the Extension Irrigation Specialist at the Irrigated Agriculture Research and Extension Center in Prosser, WA. Troy received his Ph.D. in irrigation engineering from Utah State University. Following graduation, he worked at the USDA-Agriculture Research Service Conservation and Production Research Laboratory in Bushland, TX for three years. He has been with Washington State University for over 11 years. He is also a certified agricultural irrigation specialist and is a licensed professional agricultural engineer.



Sindhuja Sankaran, Ph.D.
Assistant Professor
Biological Systems Engineering

Dr. Sindhuja Sankaran works in the Biological Systems Engineering Agricultural Automation Engineering research emphasis area. Her research focus is on sensor technologies for crop phenotype monitoring to support plant breeding, crop plant research and precision agriculture applications. Her work involves development of opto-electronic and chemical sensor technologies for non-invasive, rapid and continuous monitoring of plant health.



Li Tan
Assistant Professor
School of Electrical Engineering and Computer Science

Dr. Li Tan is an Assistant Professor in School of Electrical Engineering and Computer Science, and also on an affiliate assignment from CPAAS. He received his Ph.D. degree in Computer Science from State University of New York at Stony Brook in 2002. He also has a M.S. degree in Computer Science (1999) from State University of New York Stony Brook, a M.S. degree in Computer Science (1997) and a B.S. Degree in Physics (1992) from Fudan University in China. Prior to his arrival at WSU in 2007, Dr. Li Tan was a research engineer at Mathworks, Inc. from 2004, and before that, a research associate and Postdoctoral fellow in the University of Pennsylvania. Dr. Li Tan's research interests include software testing and verification, dynamic system modeling and analysis, logistic system modeling and analysis, and decision support for precision farming. He published more than 30 articles on journals and peer-reviewed conference proceedings. He is currently directing the Center for Experimental Software Engineering at WSU, Tri-Cities.



Matthew E. Taylor
Assistant Professor
School of Electrical Engineering and Computer Science

Dr. Matthew E. Taylor graduated magna cum laude with a double major in computer science and physics from Amherst College in 2001. After working for two years as a software developer, he began his Ph.D. work at the University of Texas at Austin with an MCD fellowship from the College of Natural Sciences. He received his doctorate from the Department of Computer Sciences in the summer of 2008, supervised by Peter Stone. Matt then completed a two year postdoctoral research position at the University of Southern California with Milind Tambe and spent 2.5 years as an assistant professor at Lafayette College in the computer science department. He is currently an assistant professor at Washington State University in the School of Electrical Engineering and Computer Science, holding the Allred Distinguished Professorship in Artificial Intelligence, and is a recipient of the National Science Foundation CAREER award. Current research interests include intelligent agents, multi-agent systems, reinforcement learning, transfer learning, and robotics.



Matthew Whiting
Associate Professor/Scientist and Extension Specialist
Department of Horticulture
Executive Board Member CPAAS

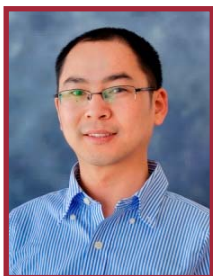
Dr. Matthew Whiting is an Associate Professor/Scientist and Extension Specialist in the Department of Horticulture and Landscape Architecture. He received his Ph.D. degree from Washington State University in 2001, his M.S. and B.Sc. degrees from the University of Guelph in Canada in 1998 and 1996, respectively. Dr. Whiting leads the stone fruit physiology program that addresses the key horticultural and physiological issues facing the industry. Dr. Whiting's research efforts are leading the integration of mechanization and automation in tree fruit through the development of planar orchard systems that are productive, precocious, profitable, and sustainable. Since 2002, Dr. Whiting has published over 60 peer-reviewed journal articles, garnered \$6M+ in grant funding, and given invited presentations around the globe.

CPAAS External Advisory Committee

Jason Brown, Mercer Canyons
Scott Korthuis, Oxbo International.
Jon Mayberry, M&MBA
Gary Snyder, C&O Nursery

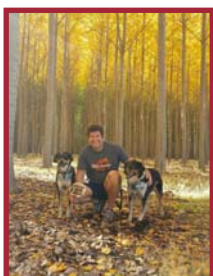
Walt Hough, Auvil Fruit Company
Jack Maljaars, Vinetech Equipment
Keith Oliver, Olsen Bros.
Scott Williams, Kiona Winery

CPAAS Support Personnel



Long He
Research Engineer

Dr. Long He is a research engineer in the Center for Precision & Automated Agricultural Systems. He received his Ph. D degree from Yanshan University in China in 2010, and his B.S degree from the same University in 2003. Dr. He joined Dr. Qin Zhang's research group as a postdoctoral research associate in 2010, and then moved University of California at Davis in 2013 working in the Dr. Stavros Vougioukas' research group as a postdoctoral scholar. In 2015, Dr. He came back to CPAAS as a research engineer. Dr. He's research interests include agricultural mechanization and automation, electro-hydraulic system in the agricultural machinery, and so on. He has been publishing in such journals as "Transactions of the ASABE", "Biosystems Engineering", "Applied Engineering in Agricultural", "HortScience" and etc. He also has been invited to review papers in five different Journals. In his personal life, Dr. He enjoys the time with his family, and also he likes reading books and playing Badminton.



Patrick Scharf
Engineering Technician III/Shop Manager

Patrick Scharf earned his B.S. in Animal Science from the University of Wisconsin-Madison in 1999 and his M.S. in Biological and Agricultural Engineering from Washington State University in 2016. Patrick's roles at CPAAS includes facilities management, research project management, project design consulting, project fabrication, safety coordination, shop management, vehicle fleet management, and administrative assistance with issues pertaining to his various roles. In his free time Patrick enjoys spending time with his happy companions, Hank and Bear, doing outdoor activities including hiking, camping, kayaking, skiing, and running. He has run races on four corners of the continental U.S. and places in between, with plans for expanding his running to venues around the world.



Linda Root
Finance/Budget Manager

Linda Root came to WSU in 2006 with of seventeen years of experience in small business management. She helped facilitate the spin-off of AgWeatherNet and has been working to assist the growth of CPAAS. She has an AA degree in Business Administration from Columbia Basin College and performs functions in Center finance management, grant management, purchasing, travel, event planning as well as Principal Assistant to the Director.

Graduate Students

Ph.D and Master students come to us from around the world as both WSU students and visiting students earning credit at their home universities helping bring our cultures together while searching for solutions to agricultural problems world wide .



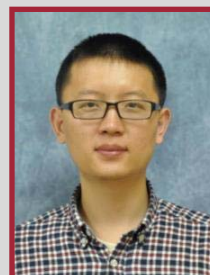
Haitham Bahlol



Santosh Bhusal



Lin Chen



Han Fu



Zongmei Gao



Kapil Khanal



Yaqoob Majeed



Parish Nalavade



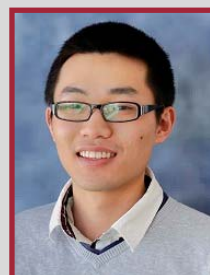
Aadit Shrestha



Abhisesh Silwal



Rajeev Sinha



Yunxiang Ye



Meng Zhang



Xin Zhang



Jing Zhang



Yanru Zhao



Hongxing Peng



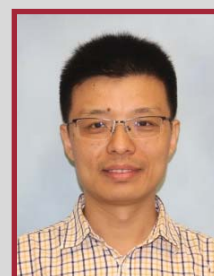
Lingxiao Quan

Juan Quiros-
VargasAnura R.
Mudiyansele

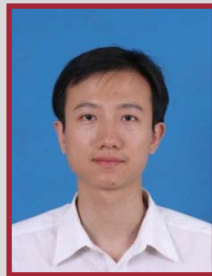
Yuanyuan Shao



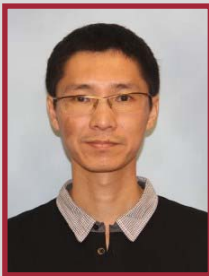
Daozong Sun



Weizu Wang



Weibin Wu



Tao Wu

Global engagement is essential to the mission of the University for achieving a world-class environment for research, scholarship, education, the arts, and engagement. Through international Memoranda of Understanding (MOUs) and International Agreements (IAs), the University fosters a network of students, alumni, teaching, and research colleagues and leaders with experiences, networks, and commitments to share in the development and execution of activities beneficial to the University, the state of Washington, and the world .

Visiting Scholars

Agricultural Automation & Engineering Club (AAEC)

Mission:

AAEC seeks to act as a liaison for enhanced collaboration and exchange of scientific knowledge among engineering students, faculty and agricultural industries. We strive to strengthen our members' active participation in different spheres of their lives, enabling them to grow professionally, academically and socially.



Activities:

AAEC focuses on engineering solutions for biological systems. It organizes as well as encourage it's members to take part in professional development, as well as academic and recreational activities. The club activities include workshops, seminars, student competitions, industry visits, movie nights, social gathering, excursions and field trips.



Officers:

President:	Carlos Z Espinoza
Vice President:	Rajeev R Sinha
Secretary:	Sanaz Jarolmaszed
Treasurer:	Afef Marzougui
Media:	Momtanu Chakraborty
Advisor:	Dr. Manoj Karkee

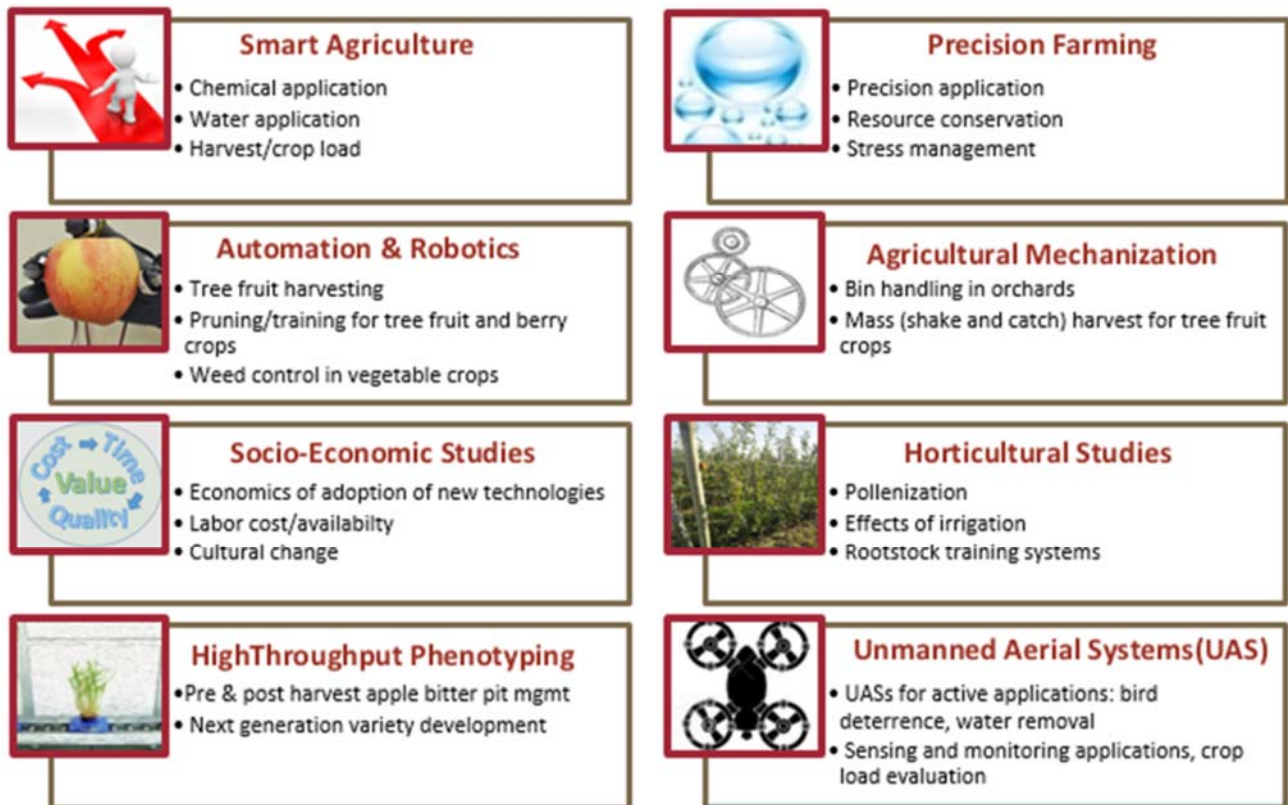
Members:

Chongyuan Zhang	Santosh Bhusal
Haitham Bahlol	Xin Zhang
Kapil Khanal	Yaqoob Majeed
Lin Chen	Zongmei Gao

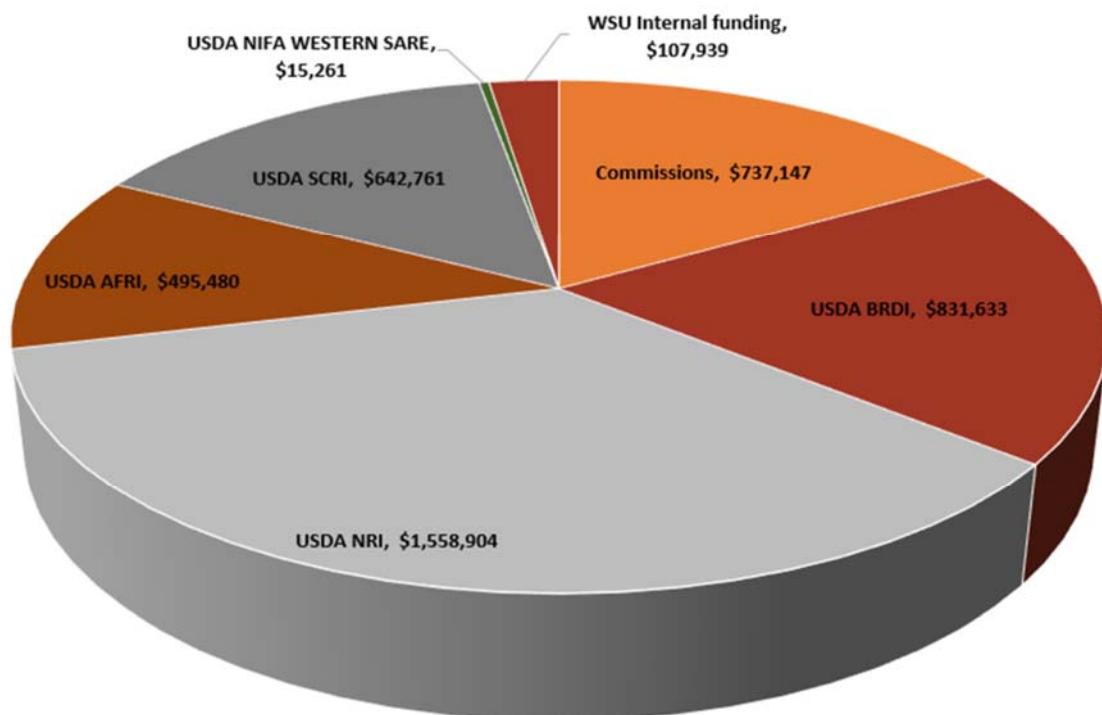


It's a RUN...derful thing to do

CPAAS Research Areas



Sponsored Projects by Agency



Sponsored Projects 2016:

Project Title	Funds Source	Amount
Deep Sub-Surface Micro-Irrigation To Increase Water Use Efficiency In Washington Vineyards (CPAAS Lead Pete Jacoby)	Commission	\$249,683
Balancing Concord Production And Water Use With Root-Zone Micro-Irrigation (CPAAS Lead Pete Jacoby)	Commission	\$14,589
Steam-Generated Supp. Heat Thermotherapy As Immediate Treatment For Prolonging Productivity Of Hlb-Infected Citrus Tree (CPAAS Lead Lav Khot)	U of Florida, USDA NIFA SCRI	\$249,859
Human-Machine Collaboration For Automated Harvesting Of Tree Fruit (CPAAS Lead Manoj Karkee)	USDA NIFA AFRI NRI	\$548,735
Intelligent In-Orchard Bin Managment System For Tree Fruit Production (CPAAS Lead Qin Zhang)	USDA NIFA AFRI NRI	\$1,010,169
Crop Signaling For Automated Weed/Crop Differentiation And Mechanized Weed Control In Vegetable Crops (CPAAS Lead Manoj Karkee)	UC Davis, USDA NIFA SCRI	\$392,902
Commercializing An Apple Harvesting System By Integrating Three Critical Technologies (CPAAS Lead Manoj Karkee)	WSU Office of Commercialization	\$48,250
Rapid Detection Technologies For Pre- And Post-Harvest Apple 'Bitter Pit' Management (CPAAS Lead Lav Khot)	Commission	\$180,628
Bio Ad-Rapid Sensing Of Dairy Manure Nutrient (CPAAS Lead Lav Khot)	CAHNRS Internal	\$18,902
Assessment Of Applications Technologies In Wine Grapes (CPAAS Lead Gwen Hoheisel)	Commission	\$53,615
Conversion of High-Yield Tropical Biomass Into Biofuels (CPAAS Lead Qin Zhang)	USDA BRDI	\$831,633
Shake and Catch Harvesting of Fresh Market Apples (CPAAS Lead Manoj Karkee)	USDA NIFA AFRI	\$495,480
Low Energy Precision Applications (CPAAS Lead Lav Khot)	CAHNRS Internal	\$27,500
Effectiveness Of Foliar Calcium Applications (CPAAS Lead Lav Khot)	Commission	\$21,282
Effects Of Subsurface Micro-Irrigation On Water Use Efficiency (CPAAS Lead Pete Jacoby)	USDA NIFA, Western Sare	\$15,261
ERI: A Proof Of Concept System Using Autonomous Unmanned Aerial System (CPAAS Lead Manoj Karkee)	CAHNRS Internal	\$13,287
Red Raspberry Trellising Demonstration Plot for Developing Automation Technologies (CPAAS Lead Manoj Karkee)	Commission	\$204,927
Unmanned Aerial Systems for Mitigating Bird Damage (CPAAS Lead Manoj Karkee)	Commission	\$12,423
Total		\$4,389,125

Summaries of Selected Research Efforts

Integrated Systems Research and Development in Automation and Sensors for Sustainability of Specialty Crops

Funding Agency: USDA NIFA (Hatch Multi State Project)

WSU Investigators: Qin Zhang; Karen Lewis and Manoj Karkee

Specialty crop producers have a need for automated production and post-harvest equipment. Aiming at filling this need by providing required research and development for such equipment, this project adapts biological concepts associated with specialty crop production, harvest, and postharvest handling into quantifiable parameters that can be sensed, develops sensors and sensing systems that can measure and interpret the parameters, and enhances the design and evaluation of automation systems that incorporate varying degrees of mechanization and sensors to assist specialty crop industries with labor, management decisions, and reduction of production costs. The success of the project will be measured by the number of prototypes the participants develop, patents they file, and assistance they provide to industry in the process of developing commercial products.



Intelligent Agricultural Systems for Specialty Crop Production

Funding Agency: USDA NIFA (Hatch)

WSU Investigators: Qin Zhang; Manoj Karkee; Lav Khot and R. Troy Peters

The recent advancement of intelligent agricultural equipment (IAE) technology has made such equipment practical and applicable for agronomic crop production. However, there are still many special challenges to be solved before the technology can be practically applied to specialty crop production. The primary focus of this project is to remove such challenges to make IAE technology practical and applicable for specialty crops production. Specific objectives of this project are to develop mechanization and

robotic solutions for production of a wide range of specialty crops, including, but not limited to, fruits and vegetables, hops, grapes and berries, and nursery crops; to find automated solutions for disease/pest monitoring, scouting and controlling in specialty crop production; to develop core technologies for computer-aided worksite management, from data collection and analysis to decision-making support; and to create effective methods for demonstrating and delivering the research outcomes to the stakeholders.



Deep Subsurface Micro-irrigation to Increase Water Use Efficiency in WA Vineyards

Funding Agency: WSDA Specialty Crop Block Grant Program

WSU Investigators: Pete W. Jacoby, S. Hossein Sadeghi, Sindhuja Sankaran, and Lav R. Khot

During 2015, vines receiving direct root-zone (DRZ) irrigation at rates reduced to 60, 30, and 15% of commercial drip irrigation (DI) had relative water use efficiency during 2015 that was 1.5, 2.5, and 5.0 times greater than did vines under surface drip irrigation. During 2016, relative water use efficiencies were 0.9, 1.4 and 2.0 that of surface drip irrigation when applied at the same respective percentages the previous year. Production efficiencies (lbs. of grapes/acre inch applied) in 2015 were 840, 1400, and 2650 for DRZ applied as 60, 30, and 15% of DI (560) and in 2016 were 752, 1147, and 1598 for DRZ compared to commercial rates of DI (818).

Balancing Concord Production and Water Use with Root-zone Micro-irrigation

Funding Agency: WA State Concord Grape Research Committee

WSU Investigators: Pete W. Jacoby, Sindhuja Sankaran, Lav Khot, Markus Keller, and Troy Peters

A Concord grape vineyard has demonstrated the potential to remain productive during extended periods of drought through the use of subsurface irrigation with considerable savings in water compared to surface drip irrigation. We determined that at mid-veraison stage of development, plant water stress, as determined by mid-day measurement of stem water potential, was substantially less in plots receiving subsurface irrigation at the 2- and 3-depths than in surface and 1-foot depths. In late July, grape clusters were consistently heavier with increase depth of irrigation delivery, with lightest clusters from the surface drip irrigation treatment and the heaviest from the 4 foot depth. Total numbers of berries were higher for the subsurface treatments than for the surface drip treatment. Average berry weight was greatest for the subsurface irrigation at the 2- and 3-foot depths of subsurface delivery. At harvest, clusters from the subsurface plots were heavier in weight than the surface drip irrigation plots, with the lower three delivery depths

Precision Sub-surface Irrigation to Regulate Wine Grape Physiology

Funding Agency: Northwest Center for Small Fruit Research

WSU Investigators: Pete W. Jacoby, Sindhuja Sankaran, Lav Khot, Markus Keller, and Troy Peters

Fruit from first year of experiment was harvested in early October 2015. Fruit weight from commercial surface drip irrigation plots averaged 10 pounds per vine. Fruit weight from sub-surface irrigation treatments averaged 9, 7.5, and 7.0 pounds per vine in plots receiving 60, 30, and 15 percent of the full commercial irrigation rate. Fruit quality was not chemically analyzed, but clusters generally had smaller individual berries and a larger number of berries per cluster than did clusters in the commercially irrigated plots. Stem water potential measurements indicated that vines receiving reduced rates of water via sub-surface irrigation had slightly more water stress than vines receiving the commercial rate via surface drip irrigation. The first year of this study was conducted under exceptional drought conditions with no rainfall during the growing season and temperatures exceeding all previous years on record. Plots receiving subsurface drip irrigation produced 4.08, 3.40, and 3.18 tons of grapes per acre at 60, 30,



and 15% the irrigation rate of the surface drip plots which yielded 4.54 tons per acre in 2015. In 2016, subsurface drip plots with irrigation rates reduced to 60, 30, and 15% of surface drip rates produced 3.79, 2.96, and 2.20 tons per acre, compared to 6.73 for surface drip at full commercial rate. The 2016 growing season began with higher temperatures in April but had cooler and wetter conditions in May and June than did the previous 2015 growing season which received no summer precipitation.

Steam-generated HMO based Thermotherapy as an Immediate Treatment for Prolonging Productivity of HLB-infected Citrus Trees

Funding Agency: U of Florida, USDA-NIFA SCRI

WSU Investigators: Lav Khot and Gwen Hoheisel

There are currently no means of treating huanglongbin (HLB) or greening infected citrus trees and immediate action is needed to manage HLB-infected orchard blocks. This project therefore investigates the biological, engineering, and economic aspects of the steam based thermotherapy technique for HLB management. WSU team's efforts are towards development of horticultural mineral oils based application techniques for tree canopy pre- and post-treatment to improve effectiveness of the thermotherapy. Team is also leveraging such efforts to develop and evaluate thermotherapy treatments in combination with the horticultural mineral oils mixtures towards the effective management of pear psyllid outbreak during various production stages in the WA State and investigating effectiveness of thermotherapy in pear decline disease management.



Human machine collaboration for automated harvesting of tree fruit

Sponsor Agency: NSF-USDA-AFRI NRI

WSU Investigators: Manoj Karkee, Karen Lewis, Changki Mo and Qin Zhang

Apple harvesting is not only labor intensive but also a time critical task requiring right amount of semi-skilled workforce at right time. The lack of mechanized harvesting system threatens the future of fresh market apple production because of the decreasing availability of farm labor force. Despite the research and development efforts over the last several decades, no commercially viable robotic harvesting systems have been available yet, primarily because of the challenges posed by unstructured farming environment. This paper presents the novel approaches investigated at Washington State University to overcome the challenges in robotic apple harvesting. First, a machine vision system capable of identifying apples in a naturally clustered and occluded conditions was developed. Artificial lighting was used to provide controlled imaging environment and capability for night time operation. Then, hand picking dynamics were studied to understand optimal picking patterns and forces required to detach apples. Based on this study, an under-sensed power grasp end-effector was designed. Vision system, robotic arm, and end-effector were then integrated and evaluated in a commercial orchard in Prosser, WA. Results showed a huge potential for in-field automated robotic harvesting system capable of accurately identifying, localizing, and picking fruit at relative high speed.



Intelligent Bin-Dog System for Tree Fruit Production

Funding Agency: USA NIFA AFRI NRI

WSU Investigators: Qin Zhang, Karen Lewis, and Long He

Harvest is the most labor-intensive operation in tree fruit orchards, requiring heavy use of seasonal labor. However, the increasingly severe shortage of labor force threatens the sustainability of the tree fruit industry in the United States. To combat this problem, the tree fruit industry needs technological innovations to assist growers in maintaining a competitive position in the global marketplace.



Preliminary conceptual development field trials indicated that the productivity of fruit picking could be improved by 50% if the collection bins within harvesting sites could be better managed. This research aims to develop an intelligent bin-managing system supported by a robotic self-propelled fruit bin carrier. A self-propelled bin managing robot research prototype has been developed, fabricated and tested in both laboratory and orchard environments. This prototype consists of a passive mechanical suspension

system and a four-wheel independent steering (4WIS) system. Supported by a multi-sensor based navigation system and an intelligent steering strategy selection algorithm, this prototype is able to switch among different steering methods to guide it accurately following the desired path under different situations. It is expected that the completion of these activities will lead to a successful development of an intelligent in-orchard bin-managing system. When commercialized, the technology can reduce labor use in bin managing during harvest season while improve the bin-managing efficiency.

Crop Signaling for Automated Weed/Crop Differentiation and Mechanized Weed Control in Vegetable Crops

Funding Agency: USDA NIFA (SCRI)

WSU Investigators: Manoj Karkee and Qin Zhang,

Stakeholders have identified effective and economical weed management techniques as a high research priority in vegetable crops, and a critical need in specialty crop production systems. Intra-row weeds decimate vegetable crops and add sharply to the cost of farm management because herbicide application against them is often inefficient and/or they require removal by hand labor.



Our long-term goal is to develop and integrate various novel engineering and automation technologies to develop cost-effective weed control systems for intra-row weed management in vegetable crops. In this project, we are developing new technologies for precise intra-row weed control and crop thinning using precision planting, crop signaling and new weed detection and actuator technologies. Component technologies will be developed at UC Davis and the University of Arizona as well before integrating them into effective and efficient weed management strategies for growers in WA, CA, AZ and other vegetable growing areas. This system will reduce the need for both hand labor and herbicides while increasing productivity, profitability and long term sustainability of vegetable production. Both organic and conventional growers will benefit greatly from our game-changing research.

Commercializing an apple harvesting system by integrating fruit removing end-effector, and fruit catching structure

Funding Agency: WSU Office of Commercialization

WSU Investigators: Mark De Kleine and Manoj Karkee;

This work continues conceptual end-effectors and catching mechanism development over the last several years for mass harvesting of apples through funding provided by in various project funded by WTFRC and USDA-NFA. The goal of this project is to improve and integrate various components into a single machine for field validation and potential commercialization.

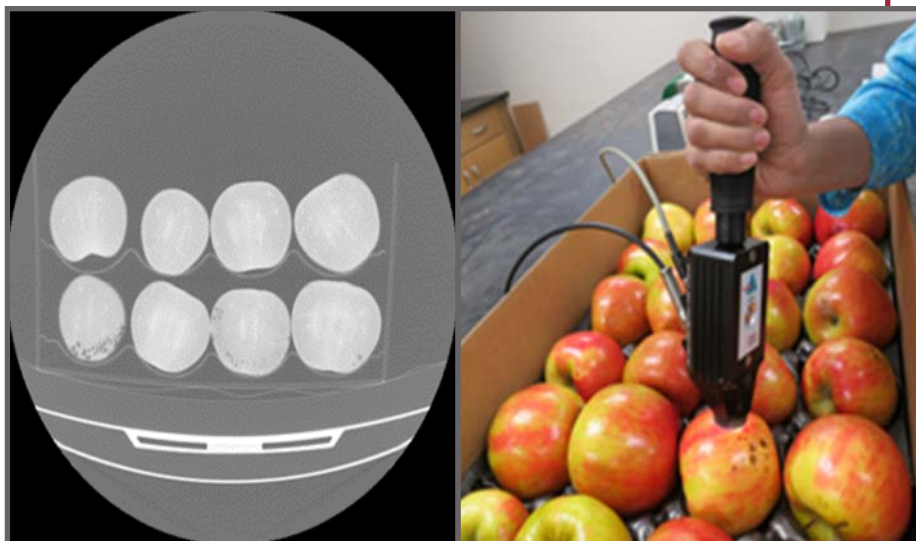


Rapid Detection Technologies for Pre- and Post-Harvest Apple 'Bitter Pit' Management

Funding Agency: WA AG/ USDA/ AMS/ Specialty Crop Block Grant

WSU Investigators: Lav Khot and Sindhuja Sankaran

Project Purpose is to develop rapid non-contact apple bitter pit detection technique(s) that will be able to identify the disorder during early to asymptomatic stages. The computer tomography (CT)-based imaging, visible-near infrared (VIS-NIR) spectroscopy, and Fourier transform infrared (FTIR) spectroscopy techniques are being evaluated for this purpose on three most susceptible apple varieties ('honeycrisp', 'granny smith', and 'red delicious') grown in the WA State. Successful detection techniques will be useful at the postharvest stage to detect and sort bitter pitted apples in fruit lots destined for the fresh market. Such rapid detection techniques will also aid growers in reducing in-field crop losses by making timely decisions on appropriate management practices.



Rapid Sensing of Dairy Manure Nutrients for Precision Applications in Agricultural Production

Funding Agency: CSANR BIOAg Program, Washington State University

WSU Investigators: Pius Ndegwa, Lav Khot, and Gopi Kafle



Precision application of manure in agricultural lands entail accurate information on its nutrients. However, existing methods are unsuitable for real-time nutrient levels estimation. This project therefore explores the near infrared spectroscopy (NIRS) as a rapid, non-destructive method of composition analyses, which can analyze several nutrients simultaneously. In order to apply NIRS technology for variable manure application under field conditions, our teams efforts are towards identify specific spectral bands, through robust computing algorithms, suitable for predicting manure nutrients (i.e. total ammoniacal N, ortho P, total N, and total P).

Assessment of application technologies in wine grapes

Funding Agency: The Washington State Grape and Wine research Program

WSU Investigators: Gwen Hoheisel, Michelle Moyer, and Lav Khot



This study compares three different sprayer designs (electrostatic, directed sprayer with disc core nozzles, and directed sprayer with air shear nozzles) for their efficacy in disease management as it relates to both general coverage and coverage types specific to different fungicide modes of action, efficiency of operation, and ease of use. A feature that makes this project unique is that a PhD student will be supported by Graduate Extension Assistantships, grant funding, and private funding from the 'Altria and Ste. Michelle Wine Estates Viticulture and Enology Fund'. This student will work with the PIs to develop a component of a 3-part curriculum for viticulture technicians.



Conversion of High-Yield Tropical Biomass into Sustainable Biofuels

Sponsor Agency: USDA NIFA BRDI

WSU Investigators: Qin Zhang and Manoj Karkee

In this project, we studied the performance of existing sugarcane harvester in harvesting various types of tropical biomass crops including sugarcane, energy cane and Bana grass. These tests were carried out in Maui, Hawaii in collaboration with Hawaii Commercial and Sugar Company. Based on these baseline studies, we identified various ways the performance of the harvesters could be improved. In addition, a physical simulation study has been carried out at WSU Prosser to optimize energy consumption in biomass base cutting. Based on the knowledge acquired from the field and lab tests, we have been improving and optimizing harvesting machines and methods for improved efficiency of tropical biomass harvesting systems.



Shake and Catch Harvesting for Fresh Market Apples

Funding Agency: USDA NIFA AFRI

WSU Investigators: Manoj Karkee, Matthew Whiting and Qin Zhang

To reduce harvest costs and dependence on labor, researchers have been seeking mechanical/robotic solutions for decades. Fruit quality and removal efficiency are the two major concerns for mechanical harvesting technology. In this work, tests were carried out with various designs of shaking and catching mechanisms for a targeted shake-and-catch harvesting system. Fruit drop tests were used to identify potential sources of bruising and to identify catching surface materials that may reduce fruit bruising. To reduce impact force on fruit during harvesting, a new catching device was designed. A dynamic test was also conducted to investigate the energy transmission to different locations in the limbs with different type of shaking mechanisms. An optimized mechanism was then evaluated for targeted shake-and-catch harvesting of various apple cultivars. It was found that the fruit removal efficiency and quality were depended on the cultivars. For the varieties tested, fruit removal efficiency varied from 70% to 90% with US Extra Fancy fruit (bruise diameter less than 12.7 mm) varying from 65% to 90%. It was found that 'Fuji', 'Jazz', and 'Pink Lady' varieties performed better in terms of fruit removal efficiency and fruit quality, showing the potential for targeted shake-and-catch harvesting of fresh market apples for certain varieties.



Machine Vision System Development for Shake and Catch Cherry Harvesting

Funding Agency: CPAAS

WSU Investigators: Suraj Amatya and Manoj Karkee

This project was aimed at identifying branches of cherry trees for harvesting cherries using mechanical



limb shakers. Automation in cherry harvesting using mechanical shakers requires sensors that can guide robotic arm to the branches. The machine vision system will help to identify branches for locating shaking points. Color cameras were used to acquire images of cherry trees. Image processing techniques were then used to segment branches from the background. Because branches were only partially visible due to occlusion by leaves and cherries, information on cherry location was also integrated with branch information to reconstruct entire cherry branches. Finally, shaking points were located in the 3D canopy structure using 3D camera images.

In-field Sensing and Decision Support System to Prevent Cherry Fruit Cracking due to Rainwater

Funding Agency: WSU-CAHNRS Emerging Research Issues

WSU Investigators: Lav Khot, Troy Peters, Matthew Whiting, Qin Zhang and David Granatstein

Fruit cracking due to early summer rain remains the key concern for fresh market sweet cherry growers worldwide. Existing mechanical rainwater removal techniques (e.g. orchard sprayers or fans, aerial helicopters)



are used by growers but there has been little systematic research on when and how much water needs to be removed from cherry canopies and the effectiveness of water removal. This project therefore focused on developing an intelligent in-field sensing and decision support system that can aid growers in managing canopy rainwater removal. Project also evaluated mid-sized unmanned aerial helicopters, an emerging technology, as a viable alternative to manned helicopters flights to disperse canopy rainwater. Developed in-field sensing system was used to conduct field experiments for optimizing mid-sized unmanned helicopter

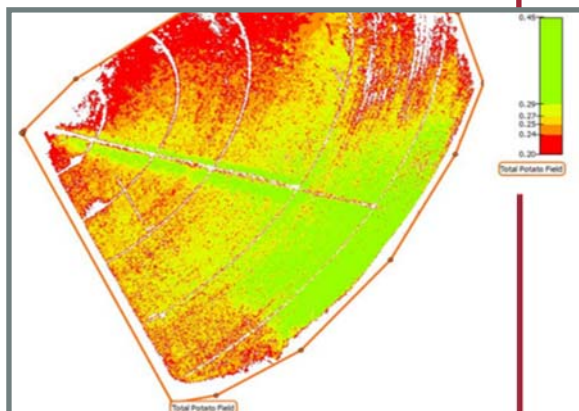
flights in modern cherry architectures and also to evaluate efficacy of an orchard air-blast sprayer in rainwater removal from such canopies.

Low Energy Precision (/Spray) Applications: Unmanned Aerial System based Rapid Evaluation for Crop and Site Specific System Adaptation in the Pacific Northwest

Funding Agency: WRC State of Washington

Investigators: Lav Khot, R. Troy Peters (WSU team) and Howard Neibling

Water inevitably is the most valuable resource of the western states and is foundation for billion-dollar agricultural industry. Keeping in view the preset situation of water and future needs under changing climate, growers need to adopt new/improved irrigation technologies, like Low Elevation Spray/Precision Application (LESA/LEPA). Such technologies have grower adoption concerns related to water use efficiencies as the canopy and air temperature driven evapotranspiration effects are unknown. Therefore, this project focuses on evaluating LESA and compare its performance with Mid Elevation Spray Application (MESA) using small unmanned aerial system (UAS) integrated multispectral and thermal imaging. In year 2016, small UAS based imaging data suggested high crop vigor and cooler canopies when potato and mint crop were irrigated with LESA compared to that of MESA. The spatial maps showed applicability of small UAS based imagery in studying site-specific suitability of LESA. Future studies are planned to relate the aerial imagery data with ground reference data for potato and mint crops and also investigate crop canopy and associate microclimate attributes throughout 2017 season.



Mechanizing Red Raspberry Pruning and Tying System

Funding Agency: Washington Department of Agriculture and WRRRC

WSU Investigator: Manoj Karkee

Washington State is the biggest producer of red raspberries in the United States. Mechanization has already been achieved in harvesting the crop, but other agricultural practices such as pruning and bundling of canes remain highly labor intensive. In this work, an automated bundling mechanism for one year old canes (primocanes) has been designed, fabricated and evaluated. A prototype for tying the canes together with adhesive tape has also been developed and evaluated. In addition, we are developing methods to identify two years old canes (floricanes) for pruning. A hyperspectral sensing system (450-950 nm range) was used for imaging red raspberry canes. Next, image classification techniques were investigated to differentiate primocanes and floricanes. The classification methods achieved an accuracy of 93.1% in detecting floricanes. Further work is being carried out to extract complete floricanes using additional techniques such as region growing .



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Commercialization

The FairWeigh™ System

Researchers Who Supported the Process: Matthew Whiting

We have supported commercialization of a field-portable system that permits growers to reimburse pickers on a weight basis (rather than the current piece-rate pay system), collects informative data on harvest, and facilitates input of harvest data into payroll software. The FairWeigh™ system keeps records of each picker's productivity, weighing the fruit they harvest over time. This system can improve the accuracy of picker reimbursement, fruit handling logistics, and decision making in the orchard. **Contact:** <http://fairweighs.com>

The Bloom Bandit

Researchers Who Supported the Process: Karen Lewis

We have supported the commercialization of The Bloom Bandit which is manufactured by Automated Ag Systems in Moses Lake, WA. This hand held thinner is used to thin blossoms in apple, sweet cherry and stone fruit trees. The hand held thinner was designed based on work completed at WSU CPAAS and the application or use in orchards is guided by the field trials conducted by WSU Extension affiliated with the center.

The first units became available in March 2014. As of Dec 31, 2015 - 98 units have been sold in the USA, New Zealand and South Africa. **Contact:** <http://automatedag.com/>

Significant Research and Development Accomplishments to Date

Smart sprayer

WSU Investigators: Francis J. Pierce, Feng Kang, Patrick Scharf, Qin Zhang

This device was developed for practicing barrier application for cutworm control and chemical control of suckers in vineyards and high-density tree fruit orchards. It uses a target recognition system to detect plant trunks, and controls a multi-nozzle spraying system rapidly and precisely applying chemicals to obtain an adequate coverage on plant trunks. Spray efficiency tests showed that targeted applications applied higher application densities at <10% of the spray volume compared to that with commercial applications with about 65-70% of the spray hitting the target under the environmental conditions tested. The trailer targeted sprayer for cutworm control performed well and would greatly reduce insecticide application costs and open up opportunities for alternative control products that are more desirable but prohibitively expensive in larger application volumes used in conventional application systems.

Contact: Qin Zhang (qinzhang@wsu.edu, or 509-786-9360) if interested in adopting or transferring this technology.

Labor Management System

WSU Investigators: Matthew Whiting, Yiannis Amatpadis, Li Tan

We have developed a real-time labor monitoring system with the ability to track and record individual picker rate/productivity during manual harvest of specialty crops. This system utilizes existing commercial harvest equipment and integrates a digital weighing scale, RFID reader, computational unit, and cloud-based software for visualization. As fruit is dumped into a standard collection bin, the system can read simultaneously a picker's ID (RFID tag) and measure the weight of fruit. This system shows potential to improve the accuracy of picker reimbursement, fruit handling logistics, and decision making in the orchard.

Contact: Matt Whiting (mdwhiting@wsu.edu)

Precision, site-specific irrigation control of an apple orchard

WSU Investigators: Troy Peters, Yasin Osroosh, Qin Zhang

This allows for site-specific and individual automatic control of various areas of an orchard. Various types of data is collected from each sub-plot within the block including soil moisture, air temperature, and canopy temperature. This data is reported back to a central control computer which analyzes the data, makes irrigation decisions, then automatically opens and closes irrigation control solenoid valves to optimally manage the irrigation for each sub-plot within the block. This setup is currently being used to test various irrigation automation algorithms.

Contact: Troy Peters (troy_peters@wsu.edu, or 509-786-9247) if interested in adopting or transferring this technology.

Hand-Held Fruit Trees Mechanical Blossom Thinner

WSU Investigators: Qin Zhang, Karen Lewis, Meng Wang

This device can be used to thin fruit tree blossom of, including but not limited to Cherry, Apple, Pear and Apricot with minor modification of the thinning head configuration. It improves thinning efficiency, reduces labor cost and improves fruit quality illustrated by trials conducted in orchards in Washington, Oregon, Pennsylvania in US, as well in Chile.

Contact: Qin Zhang (qinzhang@wsu.edu, or 509-786-9360) if interested in adopting or transferring this technology.

Knot-Tying Robotic End-effector for High-Trellis Top Twining

WSU Investigators: Qin Zhang, Long He, Henry Charvet

Twining is a labor intense task in high-trellis hop production. This robotic knot-tying end-effector was developed to perform automatic knot-tying. Concept validation tests proved that the invented knot-tying end-effector could successfully tie clove hitch knots satisfactorily on trellis wires.

Note: This technology was developed under private funding support, and is not available for technology transfer.

A Remotely Controlled Bin-dog for In-orchard Bin Handling

WSU Investigators: Qin Zhang, Long He, Yunxiang Ye, Karen Lewis

This is a remotely controllable self-propelled bin handling platform implementable in typical Washington tree fruit orchards. It is capable of traveling in typical WA/OR tree fruit orchards; and (2) capable of placing an empty bin at target locations in the row to support efficient picking and transporting a full bin to the designated bin landing area. The developed prototype- could accomplish the designated functionalities based on the tested results in both off-field environment and orchard environment in 2012 harvest season.

