WASHINGTON STATE UNIVERSITY

Center for Precision & Automated Agricultural Systems

World Preeminent, Washington Relevant

CPAAS 2014

Table of Contents

WSU Center for Precision & Automated Agricultural Systems
Washington State University
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Center for Precision & Automated Agricultural Systems
Mission Statement

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*

2014 Message from the Director

Designed to offer a framework for precision agriculture and agricultural automation efforts at WSU, the Center for Precision and Automated Agricultural Systems (CPAAS) has continued to generate high impact trans-disciplinary research and outreach outcomes in 2014. This 2014 Annual Report reflects the objectives accomplished and activities conducted by the center to implement its strategic plan.

The goal of our research program is to contribute new and valuable knowledge to the fields of precision and automated agricultural systems relevant to Washington crops. While our current major emphasis is placed on transdisciplinary solutions related to mechanical harvest of fresh market apples, including but not limited to developing machine-friendly orchard structures and tree-adaptive machinery technologies, substantial research has also been conducted within the following areas: crop phenomic sensing, automation technologies for vegetable and berry production, and mechanical harvest of biofuel feedstock. In close collaboration among sixteen affiliate faculty members from seven different departments (schools), we conducted nine trans-disciplinary, federal government funded research projects and eight industry funded projects in 2014. Based on the outcomes from those projects, the CPAAS team collectively published seventeen articles in peer reviewed professional journals and proceedings, as well as presenting twenty-seven papers and posters at national and international professional conferences and industry meetings.

To best serve the state of Washington and beyond, the CPAAS team has committed to work closely with our stakeholders through an active bi-directional outreach program. Through this program, our faculty members have offered numerous conventional educational programs to Washington agricultural growers and beyond, which include but are not limited to field days, extension presentations and publications, and popular press, video and newsletters contacts. We have also proactively approached local growers to learn their needs on technologies, and invited industry representatives to CPAAS to help us define research objectives. The strategic research plan for developing core mechanical apple harvest technology finalized in 2014 was an excellent example of valuable outcome from this bi-directional outreach.

To make our research and education program world preeminent, our faculty, postdocs, and students have been involved in organizing four international conferences or symposiums in three countries, have collectively traveled eighteen times to seven countries to give seminars and guest lectures, and to participate in other research and educational collaborations. Five students graduated with a MS or PhD degrees in agricultural and biosystems engineering and three visiting students participated in collaborative research and education at CPAAS as a part of their PhD program in corresponding home institutions.
We have also hosted eleven international visiting faculty, scholars and students for collaborative research and/or training at CPAAS.

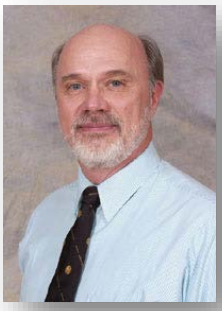
"I thank all stakeholders for their support and engagement in 2014 and expect same level of support and participation in the years to come. We continue to strive for Washington Relevant, World Preeminent research, extension and educational programs, and together we will meet the goal."

Qin Zhang

CPAAS 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 two textbooks, published over 125 peer reviewed journal articles, presented over 200 papers at 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.*



Paul G. Carter
Associate Professor
WSU Extension and Columbia County Director

Paul G. Carter joined WSU Extension in 2005 serving the Columbia County Extension Office and WSU Regional Extension. 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 Soil Science, and completed a Ph.D. (2005) in Agronomy and 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 pH and nutrient balancing. He participates in many of the county and state agricultural organizations including Vice 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.

Amit Dhingra
Associate Scientist/Associate Professor
Department of Horticulture

Amit Dhingra is a horticultural genomicist at Washington State University. His research focuses on sequencing genomes and then taking that information to produce better fruit. Dhingra led the researchers who sequenced the double haploid Comice pear, Golden Delicious double haploid apple, almond and Stella sweet cherry genomes. He received his Ph.D. in Plant Molecular Biology from the University of Delhi South Campus, New Delhi, India; with his M.S. in Botany from Agra University, India and M.S., also in Botany from University of Delhi, India.

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 are focused 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 Faculty member – Department of Horticulture
Executive Board Member, CPAAS

Dr. Pete W. Jacoby joined WSU in 1997 as CAHNRS Associate Dean, a position he held for the next 16 years during which he also served as Director of WSU Extension Agriculture Programs, Interim Director of WSU Mount Vernon-NWREC, and Director of WSU Prosser-IAREC. Prior to coming to Washington State University, Jacoby served as Director of Research at the University of Nebraska North Platte-WCREC and District Director of the West Central Extension District. Jacoby also served 17 years with Texas Agri-Life – Research at Vernon as a Research Project Leader before being named as Interim Director in his final year there. Jacoby is a 1966 graduate of Texas A&M University, and earned M.S. and Ph.D. degrees at the University of Wyoming - Laramie. His research interests are focused on dynamics of perennial woody plant root systems under differing irrigation schedules and delivery systems. He is an active member of the American Society of Agricultural and Biological Engineers.

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

Dr. Manoj Karkee is an affiliated faculty member to the center and is an assistant 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 mechanization 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 '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 in the editorial board of 'Image Processing in Agriculture', and in the editor advisory board of 'Computers and Electronics in Agricultyure'.

Lav Khot
Biological Systems Engineering
Assistant Professor

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 extenion 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 dvision of Transactions of ASABE journal.

Karen Lewis
WSU Regional Tree Fruit Specialist
Grant-Adams Area Extension
Executive Board Member, CPAAS

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
Assistant Professor
School of Mechanical and Materials Engineering

Dr. Changki Mo is an affiliated faculty member to the center and is an assistant 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

Dr. Stefano Musacchi has been named the Endowed Chair of Tree Fruit Physiology and Management at the Department of Horticulture, Washington State University in August 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.

Troy Peters
Extension Irrigation Specialist/Associate Professor
Biological Systems Engineering

Dr. 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 6 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. 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
WSU Tri Cities

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 Washington State University, TriCities.

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

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.

Dr. 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 Support Staff

Robert Dickson
Information Systems Coordinator

Robert grew up in Seattle and graduated from the University of Washington with a degree in Political Science. His passion for computer technology led him to own and operate a small business in computer retail sales and service in Kennewick, WA for a number of years. Most recently Robert worked at Pacific Northwest National Laboratory in Richland, WA supporting IT in Information Management Services. Robert has a passion for technology and loves working within the research community**.**

Patrick Scharf
Engineering Technician III

Patrick earned his B.S. in Animal Science from the University of Wisconsin-Madison in 1999. Scharf is currently working toward a Masters in Biological and Agricultural Engineering, here at WSU. Scharf's role at CPAAS includes management of facilities, research project management, project design consulting, project fabrication, safety coordination, shop manager, vehicle management, and providing assistance with administrative issues as they pertain to his activities. Scharf is also a coauthor on CPAAS publications and a listed contributor on invention disclosures to which he has made a significant contribution.

Linda Root
Finance Budget Manager

Linda 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.

Education & WSU International Programs at CPAAS

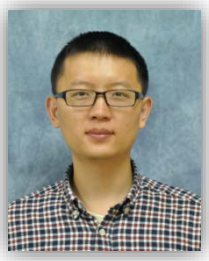
Many of today's pressing global challenges (such as food, environmental, energy and water security) align well with WSU's strengths and expertise. Solutions to these complex challenges require interdisciplinary and international cooperation.

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


Youchun Ding


Feng Tao


Han fu


Gaili Gao


Jun Li


Wesley Santiago


Junhua Tong


Kehui Xiao


Satoshi Yamamoto


Long Yu


Meng Zhang

Post-Doctoral Research Associates

Peter Ako Larbi

Shaochun Ma

Graduate Students

Suraj Amatya

Mark De Kleine

Xaiolei Deng

Aleana Gongal

Lei Li

Yasin Osroosh

Wesley Santiago

Patrick Scharf

Abhisesh Silwal

Junhua Tong

Yunxiang Ye

Jingjin Zhang

Jianfeng Zhou

Agricultural Automation & Engineering Club

Our Missions

To encourage collaboration and exchange of knowledge between engineering students, faculty and the department while fostering a close relationship among them and helping in developing both professionally and academically.

Activities

We primarily focus on engineering solutions for biological systems. We organize/take part in professional development, academic and recreational activities. The activities may include workshops, seminars, student competitions, field trips or sports.

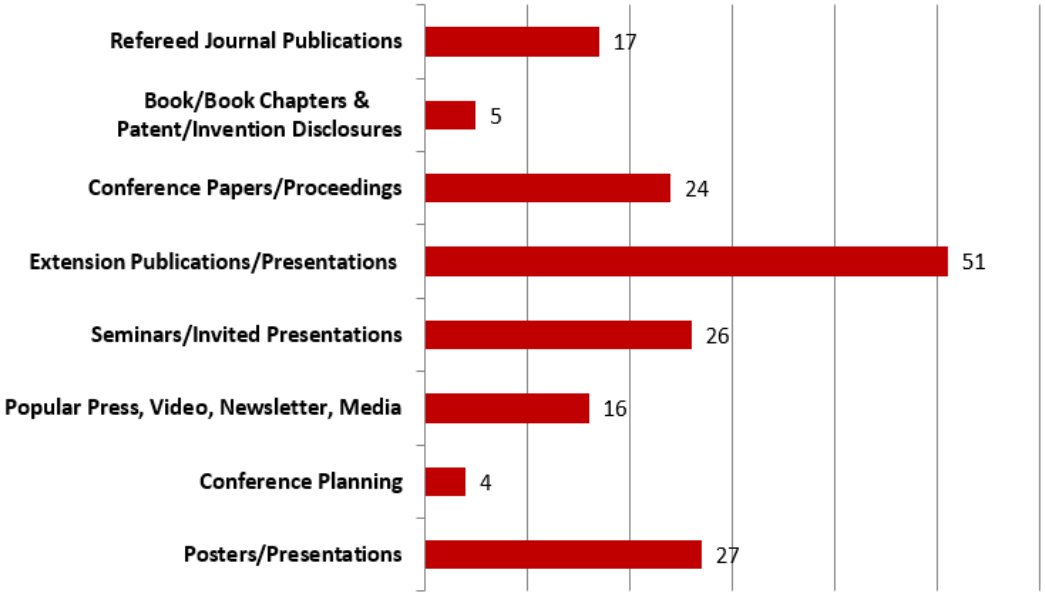
Seminar on
'Professional writing for scientific research papers'

AAEC Bowling Night 2014

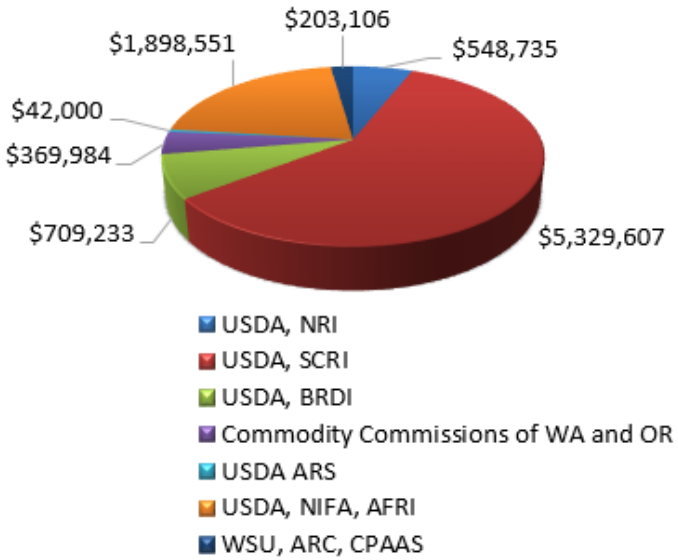
President: Suraj Amatya
Vice President: Carlos Luis Zuniga
Secretary: YunXiang Ye
Treasurer: Abhisesh Silwal
Advisor: Manoj Karkee

Members:
Aadit Shrestha
Haitham Bahol
Patrick Scharf
Seyedehsanaz Jarolmasjed

Research and Extension Outputs



2014 Funding Sources $9,101,216



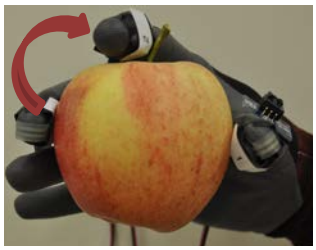
Sponsored Projects 2014

- Development and Optimization of Solid-Set Delivery Systems for Resource Efficient, Ecologically Sustainable Apple and Cherry Production, (USDA SCRI, CPAAS Leader: Zhang)
- Precision Canopy and Water Management of Specialty Crops through Sensor-Based Decision Making (USDA SCRI, CPAAS Leader: Zhang)
- Human-machine collaboration for automated harvesting of tree fruit (USDA NRI, CPAAS Leader: Karkee)
- A Total Systems Approach to Developing a Sustainable, Stem-free Sweet Cherry Production, Processing, and Marketing System (USDA SCRI, CPAAS Leader: Whiting)
- Conversion of High-Yield Tropical Biomass into Sustainable Biofuels (USDA BRDI, CPAAS Leader: Zhang)
- Eight(8) projects from Commodity Commissions of WA and Oregon: (CPAAS Leaders: Zhang, Karkee, Lewis, Whiting)
- Multi- and Hyper-spectral Imaging for Potato Stress Sensing (USDA ARS, CPAAS Leader: Karkee)
- Intelligent In-Orchard Bin Managing System for Tree Fruit Production (USDA NIFA NRI, CPAAS Leader: Zhang)
- Shake and Catch Harvesting for Fresh Market Apples (USDA NIFA NRI, CPAAS Leader: Karkee)
- Crop Signaling for Automated Weed/Crop Differentiation and Mechanized Weed Control in Vegetable Crops (USDA SCRI, CPAAS Leader: Karkee)
- Emerging Issues Research & Student Projects (WSU, ARC, CPAAS: Zhang, Karkee, Khot)

2014 Project Summaries

Human machine collaboration for automated harvesting of tree fruit

Sponsor Agency: NSF-USDA-NRI
Karkee, M.*; Lewis, K.; Mo, Changki; Zhang, Q.



Harvest is the most labor-intensive operation in apple and pear orchards, requiring heavy utilization of seasonal labor. The development of robotic technology for harvesting tree fruit has achieved only limited success due to insufficient speed and accuracy of fruit recognition and removal. Lack of such technology is a crucial problem for the long-term sustainability of the domestic tree fruit industry because the cost of labor continues to increase and the availability of a semi-skilled labor force is becoming increasingly uncertain. The long-term goal of this work is to reduce dependency on human labor through mechanization and human-machine collaboration while increasing yields of premium quality fruit. The overall objective is to develop a framework for knowledge transfer and collaboration between human and machine. This objective will be achieved through the understanding of the dynamics of the hand picking of fruit, development of an effective end-effector based on the knowledge of hand picking, and a framework of hardware and software for optimal collaboration between human and machine for fruit detection. A trans-disciplinary team of experts is involved in this project, which is crucial for the successful completion of these activities. This project was initiated in fall 2013 and significant progress has been made in understanding fruit removal dynamics, fruit detection and development of end-effector and manipulator for robotic apple picking.

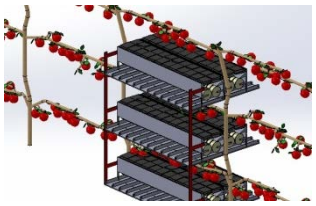
Developing Apple Harvesting Techniques

Sponsor Agency: WTFRC, USDA NIFA
Karkee, M.*; De Kleine, M.; Lewis, K.M.; Zhang, Q.

Fresh market apple harvesting is currently done using manual labor in all fruit growing regions in the world. Because the labor cost is increasing and labor availability is increasingly uncertain, mechanized harvesting solutions are critically important for the sustainability of apple industry. In this work, two concepts for fresh market apple harvesting were developed and tested for trellised orchards in Washington State. The harvesting technique used bi-directional rotating rubber wheels, and a shaking mechanism to detach apples from a fruiting wall trellised-branch. Rotation was varied between clockwise and counter-clockwise directions. Shaking mechanism was used to apply patterned and linear signal to the branches. Prototype machines were developed and evaluated in WA orchards. Performance of different techniques depended on apple varieties.

Shake and Catch Harvesting for Fresh Market Apples

Sponsor Agency: USDA NIFA
Karkee, M.*; Whiting, M.; Zhang, Q.



Traditional apple harvesting requires a large, semi-skilled workforce for a short time. Shake-and-catch technology has been successful in harvesting fruit for the processing market, but no commercial success has been achieved in harvesting fresh market apples because of fruit damage. Lack of such technology is a crucial problem for the industry because the cost of manual labor is increasing and labor availability is increasingly uncertain. In this project, we aim to develop a fresh-market apple harvesting technology to reduce dependence on seasonal labor. Research methods include identification of mechanisms for localized shaking and catching, and their integration and evaluation in commercial orchards. First, we will study the effects of different combinations of shaking pattern, amplitude and frequency in fruit removal efficiency. Second, various fruit catching, deceleration and singulation mechanisms will be evaluated to maximize fruit collection and minimize damage. In addition, strategies for tree training, pruning and thinning will be studied to improve the ease of catching surface insertion into tree canopies. Overall, our system will minimize the impact force between fruit and catching surface and lessen fruit-to-fruit contact, the two primary causes of fruit damage.

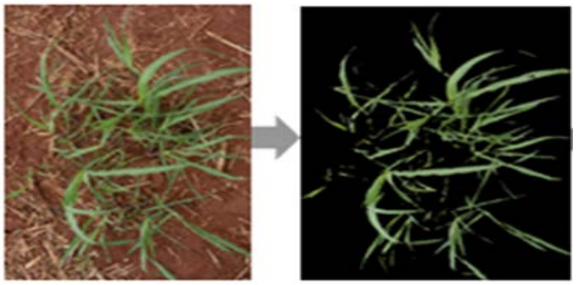
Intelligent Bin-Dog System for Tree Fruit Production

Sponsor Agency: WTFRC
Zhang*, Q.; Lewis, K.M.; He, L.

Harvest is the most labor-intensive operation in tree fruit orchards, requiring heavy use of seasonal labor. The tree fruit industry needs technological innovations to assist growers in maintaining a competitive position in the global marketplace. Preliminary conceptual development field trial results 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-management system supported by a robotic self-propelled fruit bin carrier. If successfully developed, such a technology could help to solve a crucial problem for the long-term sustainability of both the domestic tree fruit industry and other industries facing similar challenges. The primary goals of this research are to create core technologies for robot-human and robot-environment interfaces needed in building an intelligent bin-management system implementable in the natural environment of tree fruit orchards. The overall objective is to develop a system capable of placing and collecting bins in a fruit tree orchard, which will reduce labor requirements and maximize worker productivity. The objective will be achieved by developing algorithms, integrating them into a self-propelled robotic bin carrier, and then validating the system in a working orchard environment. Involvement of trans-disciplinary expertise from the collaborative WSU and OSU project team, availability of well-equipped laboratories, and access to both research and commercial orchards all facilitate the successful completion of these activities.

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

Sponsor Agency: USDA NIFA (SCRI)
Karkee, M.*; Zhang, Q (WSU Team)



Stakeholders have identified effective, and economical management techniques as a research priority in vegetable and a critical need in crop production systems. row weeds decimate vegetable crops and add to the cost of farm sharply 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. We will develop new engineering technologies for precise intra-row weed control and crop thinning using precision planting, crop signaling and new weed detection and actuator technologies. These technologies will be developed at UC Davis (lead institution) and the University of Arizona 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.

Conversion of High-Yield Tropical Biomass into Sustainable Biofuels

Sponsor Agency: USDA NIFA (BRDI)
Zhang*, Q.; Karkee, M. (WSU Team)

In this project, we are undertaking tasks of improving harvesting mechanisms for effective and efficient harvesting of tropical crops for biomass. The target crops are sugar cane, energy cane, and Bana grass. We have been performing laboratory simulation studies to identify limitations of current cutting mechanism. At the same time, we carried out field evaluation of existing machine to collect baseline machine performance data in Hawaii sugarcane, Bana grass and energy cane fields. Based on the knowledge acquired from the field and lab tests, we will improve and optimize cutting and feeding mechanism for tropical biomass harvesting. Improved mechanisms will be evaluated in the field in Hawaii.

Precision Canopy and Water Management of Specialty Crops through Sensor-Based Decision Making

Sponsor Agency: UC Davis USDA NIFA (SCRI)
Zhang*, Q; Whiting, M.D.; Tan, L.; Peters, R.T. (WSU Team)

This project is a subcontract to a SCRI project with UC Davis as the leading institution. WSU team is contributing to nine different objectives and is playing critical roles in a few objectives. We have been refining the sensor system and perform the canopy PAR/shape assessment in tree fruit orchards; and we have been developing a research-grade sensing and mapping system to gather the data for each plant using multiple sensors to predict plant water status. WSU investigators have been leading the development of a visualized decision support system to meet the decision support needs of growers, university researchers; and have been involved in the development and implementation of site-specific application of water and fertilizer using autonomous units. Collaborating with external partners, we have also been conducting studies on assessing social impacts of developed innovative technologies through collecting, analyzing and summarizing collected data.

Mechanizing Red Raspberry Pruning and Tying System

Sponsor Agency: Washington Department of Agriculture and WRRC
Karkee, M.* (WSU team)

Cane management in red raspberry production is highly labor intensive. Labor availability is uncertain at best and labor cost is increasing. Currently, Washington growers estimate the pruning and tying cost in red-raspberry production to be from $500 to $800 per acre. In addition, labor is at risk for chronic and acute injury. Mechanization has the potential to substantially reduce labor use from cane management. In this project, WSU is collaborating with Washington Red Raspberry Commission and USDA ARS to establish a red raspberry plot in Prosser, WA and collected preliminary data with different horticultural systems established in Mt. Vernon, WA. We are also developing and evaluating a mechanism for red raspberry cane bundling and tying.

A Total Systems Approach to Developing a Sustainable Stem-Free Sweet Cherry Production, Processing, and Marketing System

Sponsor Agency: USDA NIFA (SCRI)

Whiting*, M.D.; Zhang, Q.; Karkee, M.; Dhingra, A.; Oraguzie, N.; Ross, C. (WSU Team)

This research is part of a large multi-state, multi-disciplinary research project funded by the USDA's Specialty Crop Research Initiative (SCRI). The overall research goal is to develop a highly effective sweet cherry production, processing, and marketing system with effective research and outreach programs addressing the entire production chain. Researchers are working closely with industry to solve the challenges of a declining labor supply. The rationale behind this research project is clear: to remain profitable and sustainable, the sweet cherry industry must improve harvest labor efficiency without reducing consumer appeal of fruit. Objectives are addressed in horticulture, genetics & genomics mechanical harvest technologies, packaging & consumer acceptance and economics.

Development and Optimization of Solid-Set Canopy Delivery Systems for Resource-Efficient, Ecologically Sustainable Apple and Cherry Production

Sponsor Agency: USDA NIFA (SCRI)

Brunner*, J.; Zhang, Q.; Karkee, M.; Whiting, M.; Hoheisel, G. A. (WSU Team)

This project is a subcontract to a SCRI project with Michigan State University and co-directed by Dr. Brunner of WSU. In this project, we have formed a multidisciplinary research and extension team from three of the major fruit-producing states to develop, evaluate, and deliver resource-efficient, innovative management technologies and tactics for apple and cherry production systems. It aims to establish innovative delivery technologies for canopy inputs to address critical fruit production needs as identified by commodity PMSPs and the Technology Roadmap for Tree Fruit Production. Direct outcomes of system implementation include: technological feasibility, and economic and agro ecosystem impacts. Sociological research has been focusing on how these integrated technologies impact urban-farm relations, barriers to grower adoption, and how these factors can inform better extension and educational programmatic efforts.

Mechanical Pruning in Apple, Sweet Cherry and Pear

Sponsor Agency: WTFRC

Lewis*, K.M.; Musacchi, S.; Whiting, M.

This project is designed to evaluate tree response, equipment and orchard requirements for mechanical pruning in apple, sweet cherry and pear. Trials in apple and sweet cherry were established in 2014. The equipment used in the 2014 trials was a Gillison center mount hedger (Benzonia, MI) with the capacity to run horizontal for top working trees and vertical for hedging. Treatments included mechanical thinning and thinning done by hand at different tree growth stages. Tree measurements include wood and leaf removal, regrowth, and return bloom. Fruit quality measurements include fruit number, fruit weight, fruit damage, and fruit color. Time to complete tasks and resulting economic impact will be reported. Preliminary results indicate that mechanical pruning is 23X faster than hand pruning in cherry and 2-4X faster in apple. Wood and leaves removed at dormant timing using hand pruning is 2X greater in cherry and 3X greater in apple when compared to mechanical treatments. 2014 trials indicated that use of the Gillison Hedger can result in dirty cuts on wood that is not secure and 6.5% of apple fruit was damaged in the summer 12-20 leaf stage treatments. The fruit could easily be identified and removed during the green fruit thinning operation. In 'Cripps Pink' the dormant timing for mechanical pruning resulted in significantly fewer number of fruit, lower pounds of fruit per tree and lower yield efficiency when compared to hand pruning at dormant timing. Mechanical pruning at dormant timing also resulted in significantly fewer number of fruit per tree, lower pounds of fruit per tree, lower TCSA and yield efficiency when compared to mechanical pruning at summer timing. Fruit color, hue, and maturity showed a response to pruning method and timing. The Gillison is a center mount but is still a challenge for narrow orchard tractors. 2015 trials will include additional apple and cherry trials and a pear trial. Mechanically pruning treatments in apple and pear will be done with a new hedger manufactured by Lagasse Works Inc. (Lyons, NY).

3D Machine Vision for Improved Apple Crop Load Estimation

Sponsor Agency: WTFRC
Karkee*, M.; Zhang, Q.; Lewis, K.M.

Accurate estimation of apple crop-load is essential for efficient orchard management. In this work, we designed an over the row platform to capture images from two side of apple canopies to minimize the occlusions and improve the accuracy of crop-load estimation. A color camera, a 3D camera and an orientation sensor were mounted in the sensor platform and moved down apple rows in three different commercial orchards of Allan Bros. Inc., Prosser, WA. Overall, the images of apples trees were successfully captured from both sides of the row using this platform. Taking images from dual sides showed to be fruitful as more apples were identified which were occluded when viewed from a single side. An apple detection algorithm and a 3D mapping algorithm was used to count apples while avoiding duplicate counting of apples that were visible from both sides of tree canopies. Crop-load estimation improved by approximately 20% when imaged from two sides compared to that with single-side imaging. Increased accuracy of crop load estimation on a block by block basis would lead to increased efficiencies, a higher level of risk management and increased profitability.

Multispectral and Hyperspectral Image Analyses of Potatoes under Different Nutrient Management with Center Pivot Irrigation

Sponsor Agency: USDA ARS Prosser Vegetable and Forage Crop Research Unit
Karkee, M.*; Zhang, Q. (WSU team)

This research project aims to investigate the feasibility of non-destructive estimation of nutritional status of potato canopy using multispectral and hyperspectral imaging and prediction of tuber yield and quality response to variable nutrient management under pivot irrigation. Spectral characteristics of vegetation are a quantitative measure and can offer a non-destructive method to assess crop nutrition; biomass production; yield and quality of crop products. This type of sensing technology has been successfully developed for detecting nitrogen stress in agronomic crops, but little research has been reported on effectively and accurately measuring the nutritional status of potato plants in irrigated production systems using multispectral images. This project investigated the application of such technology to potato production under center pivot irrigation. Experiments were carried in green house and in the field to collect spectral signature of plant managed with different levels of water and nitrogen. A good correlation between changes in spectral signature and changes in water and nitrogen levels was observed.

Systems Approach to Superior Pear Fruit Quality

Sponsor Agency: NW Pear Bureau

Dhingra*, A.; Evans, K.; Sablani, S.; Zhang, Q.; Ross, C.

This project uses a systems approach to establishing pear-specific knowledgebase. In the past recommendations for improving pear production, processing and packaging have heavily relied on systems established for apple. However, pears are not apples, and there is an urgent need to reevaluate our approach in how to develop pear-specific solutions for production, post-harvest and processing stages. We plan to utilize this project as a platform to successfully compete for federal USDA-SCRI grant. The specific objectives of this proposal include: to evaluate and devise efficient orchard systems that are amenable to mechanized pruning and harvest using labor assist platforms; to assess the effectiveness of vigor-retarding chemicals like Apogee and Treehold by understanding the underlying gene function; to test the role of cuticle as it relates to fruit quality using microscopy; and to evaluate alternative fruit sanitization platforms like UV or gamma rays in lab settings.

Unmanned Aerial Systems (UASs) for Mitigating Bird Damage in Blueberry Crops

Sponsor Agency: Washington Blueberry Commission

Karkee, M.*, Leachman, J., Taylor, M., and Zhang, Q.

Every year, significant fruit yield loss is attributed to bird damage in WA and other parts of the country. The issue is particularly prevalent to Washington and Oregon vineyards but is also a critical issue for cherries and other fruits including blueberries and raspberries. Washington State grape, blueberry, cherry, and Honeycrisp apple farmers lose $80 million annually to bird damage. Netting, auditory scare devices, visual scare devices, chemical applications, and active methods such as trapping, falconry, and lethal shooting are the most common ways that bird control is practiced. However, netting is the only method viewed by most farmers as effective, which also is costly and lethal to a host of wildlife. In this work, we plan to investigate the efficacy of using fixed wing, quadrotor and/or other Unmanned Aerial Systems (UASs) to deter birds from vineyards. After showing that human-guided UASs can effectively deter birds, our longer term goal is to apply machine learning techniques to autonomously deter birds out of an area.

Field Phenomics Platform Development

Sponsor Agency: WSU, ARC

Pumphrey*, M.; Brown, D.; Carter, A.; Garland-Campbell, K.; Hulbert, S.; Knowles, R.; Steber, C.; Zhang, Q.

This project is to develop a field research platform and conduct preliminarily tests based on an automatically navigated and steered agricultural tractor. Field-based sensor and imaging devices will be mounted on the platform to efficiently collect data related to crop productivity, input-efficiency, and health while simultaneously applying methods to determine and account for spatial variation due to soil heterogeneity. This automated field research platform, with state-of-the-art imaging, sensing, and positioning/guidance systems, will be capable of rapid, in situ, assessment of crop nutrient and water status, crop health, vigor and productivity, and other important characteristics.

Sub-surface Micro-irrigation to Conserve Water and Advance Precision Vineyard Management

Sponsor Agencies: WSU Ag Research Center - Emerging Research Issues Grant Program; Wine Advisory Committee - WA State Grape and Wine Research Program; and Northwest Center for Small Fruit Research

Jacoby, P.W.*; Peters, R.T.; Sankaran, S.; and Khot, L.R.

Three separate projects were funded to determine potential abilities of grapevine root systems to maintain or increase water use efficiency by delivering water at various depths (1-4 feet) in the soil. Rather than using buried lines with drip emitters in contact with soil and subject to damage by burrowing rodents, covered drip emitters were placed on top of vertically inserted delivery tubes into which water was supplied from above-ground standard drip hose via micro-tubing. Vine root growth responses are quantified from digital photography from a camera inserted through a clear polyvinyl tube (mini-rhizotron) at two week intervals throughout the growing season. Physiological plant responses to treatment effect are estimated by measurements of mid-day xylem pressure potential and infrared determination of CO2 use as a measure of photosynthesis. These measures are compared with color enhanced spectral imagery from aerial and ground based cameral systems for early detection of plant water stress under various irrigation regimes.

Machine Vision System Development for Shake and Catch Cherry Harvesting

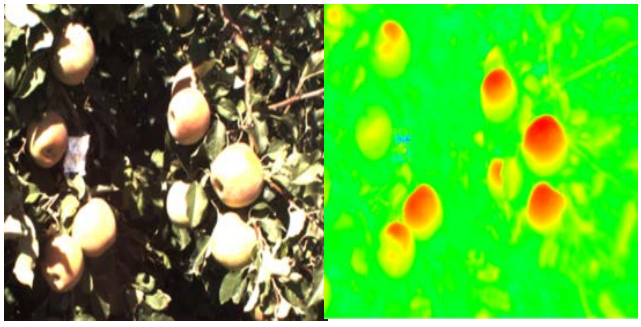
Sponsor Agency: CPAAS
Amatya, S.; Karkee, M.

This project is 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 is also integrated with branch information to reconstruct entire cherry branches. In the future, shaking point localization in 3D space will be studied.

Modelling fruit surface temperature dynamics for automate fruit evaporative cooling

Sponsor Agency: CPAAS
Li, L.; Peters, T; Zhang, Q

Sunburn of fruit surfaces exposed to direct sunlight is a major economic problem of marketing fresh apples. The aim of this work is to develop and test a model for simulating fruit surface temperature based on climate data. This model would take into account the effect of different sun exposures and leaf shading. Fruit surface temperature in orchard was monitored by infrared camera. Climate data (air temperature, humidity, solar radiation and so on) were measured. The model was developed based on an energy balance as well as field data. The model described apple thermal behavior, improving upon the estimates usually made by only air temperature. It will define temperature and time thresholds necessary to automate a fruit evaporative cooling system.



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

Sponsor Agency: USDA NIFA (Hatch Multi State Project)

Zhang*, Q.; Tang, J.; Sablani, S.S.; Lewis, K.M.; Karkee, M.

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

Sponsor Agency: WSU ARC (Hatch)

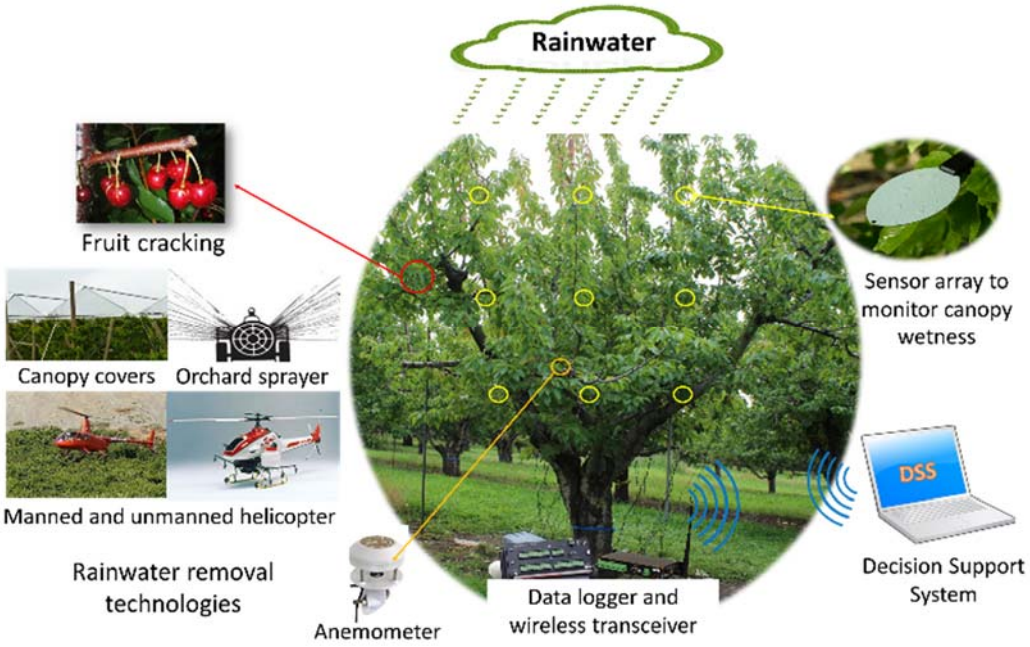
Zhang*, Q.; Karkee, M

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.

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

Sponsor Agency: WSU-CAHNRS 2014 Emerging Research Issues
Khot, L. R.; Peters, T., Zhang, Q.; Granatstein, D.; Whiting, M

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. Through this research efforts, we have developed an in-field sensing to monitor real-time rainwater level of orchard canopies to assist grower decision making. Sensing system constitutes array of wetness sensors placed in canopies transmitting logged data in real-time to base station over wireless network. In year 2015, we plan to extensively test the robustness of the sensing system and develop decision rules through field studies. Field studies towards evaluating efficiency of orchard sprayer airblast, manned and unmanned helicopter downwash in rainwater removal will be conducted.



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Significant Research and Development Accomplishments to Date

1. **Smart sprayer**
   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.

2. **Precision, site-specific irrigation control of an apple orchard**
   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

3. **Labor Management System**
   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)

4. **Hand-Held Fruit Trees Mechanical Blossom Thinner**
   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.

5. **Knot-Tying Robotic End-effecter for High-Trellis Top Twining**
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.

6. **A Remotely Controlled Bin-dog for In-orchard Bin Handling**
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-one could accomplish the designated functionalities based on the tested results in both off-field environment and orchard environment in 2012 harvest season.

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