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INVESTIGATOR: Zhang, QI, .; Karkee, MA, .; Khot, LA, .; Peters, R, TR.; Neibling, HO, .; Stroh, RI, .; Brown, DA, .

PERFORMING INSTITUTION:
WASHINGTON STATE UNIVERSITY
240 FRENCH ADMINISTRATION BLDG
PULLMAN, WASHINGTON 99164-0001

RESEARCH ON AUTOMATION AND MECHANIZATION FOR SPECIALTY CROP PRODUCTION

NON-TECHNICAL SUMMARY: Specialty crop industries in the State of Washington are facing growing global market pressures, which threaten their long term viability. Demand for high product quality and safety, compliance with environmental protection laws, threats from invasive insects and diseases, and rising energy and labor costs only amplify the challenges. Another critical challenge in specialty crop production is that field operations are highly labor intensive. The industries need technology innovations, which can assist them in maintaining a competitive position in the global marketplace by addressing these challenges. Operating from a position of high labor cost and more rigorous regulations, the industry needs to adopt mechanical and/or automated approaches to solve production system problems. This proposed research will focus on developing fundamental and applied technologies for intelligent agricultural machinery for mechanized, automated, and/or precision specialty crop productions. The ultimate goal of intelligent agricultural machinery technology research is to provide US specialty crop producers a practical way of performing field operations more efficiently, with less dependence on human labor, and in amore environmental friendly manner. Such advancement willhelp producers realize their goals on productivity, product quality, and profitability.

OBJECTIVES: The primary focus of the proposed project is to develop mechanization and automation solutions for specialty crops production, including fruit harvesting, fruit tree pruning, pest detection and control, and maintenance and/or improvement of food quality and safety.Specific objectives of this project are to develop:(1) mechanization and robotic solutions (e.g., harvesting, produce handling, tree pruning machine) for production of a wide range of specialty crops, including, but not limited to, fruits and vegetables, hops, grapes and berries, and nursery crops;(2) automated and precision solutions for pest (e.g.,disease, insect, weed) monitoring, scouting and control in specialty crop production;(3) core technologies for computer-aided worksite management, from data collection and analysis to decision-support systems; and(4) effective methods for demonstrating and delivering research outcomes tostakeholders.

APPROACH: This research will use both demand-driven and technology-driven approaches in conducting the proposed intelligent agricultural machinery and system research and development. In demand-driven approach, the research will be originated from an unmet market demand for a particular type of machinery or technology.The end-users of the machinery/technologyprovide ideas on how it should work based on their experiences in performing the field work using similar machinery or technology. To find a solution for solving this type of problem, we plan to create an invention space by specifying the actual demand of the end-users, analyzing the causes of why existing products for the same or similar operations cannot meet the needs, investigating the feasibilities of applying alternative operations to achieve the same goal, and then searching for practical solutions to solve the problem. The research outcomes will have to go through a commercialization process to make the developed technologies available to end-users in the form of innovative products. Based on this guideline, a five-step approach, consisting of: (1) operation observation and analysis; (2) analysis of existing technologies for similar tasks; (3) define design specifications for conceptual devices/systems based on the identified operation requirements and functionality constraints; (4) development of conceptual systems then evaluate their functionality in a laboratory setup; and (5) development of prototype systems and then validation in actual field operations, will be used for the demand-driven component of research. In a technology-driven approach, the research will be stimulated by technology advancement in different areas. Some basic features of this type of research include that there is no "off-the-shelf" technology available to solve the defined problem and an end-users unfamiliar "innovative" solution is often expected from the project which requires an education process to make users become comfortable using it. Our proposed research strategy is to search for a possible solution for a poorly defined problem - to start the process by creating an invention space which conceptualizes a few feasible alternatives to current processes or operations to reflect the desired outcomes; and searching, adopting and/or modifying relevant technologies to make them usable to the process of concern. Based on this guideline, a different five-step approach, consisting of (1) definition of an ideal demand for the process of interest; (2) conceptualization of feasible alternative processes; (3) technology innovation to find solutions for the alternative process based on the relevant technologies; (4) development of a conceptual system to assess the practicality of the solution using a research platform; and (5) development of a prototype device and validation of the prototype in actual specialty crop production fields, will be used.

KEYWORDS: agricultural automation; intelligent agricultural equipment; mechanized precision farming; specialty crops

PROGRESS: 2016/10 TO 2017/09
Target Audience:Specialty crop producers, agricultural equipment manufacturers and technology providers who are seeking new solutions to improve specialty crop production and efficiency. Because of the user-centered research nature of this project, the end-users of developed technologies, as well as fellow researchers and general public in Pacific Northwest (PNW) region, are included in our research outcome disseminating group, with frequent communications to get feedback from them. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided?Graduate students (9 total), post-doctoral research associates (2 total), exchange graduate students from foreign institutes (2 total) and visiting scholars (6 total) working on the project took advantages of opportunities to develop their wide-spectrum of research skills and professionalism in a collaborative working environment. Four different field days were held to demonstrate the LEPA, LESA, and MDI sprinkler configuration options for growers. Peters started advising 2 new PhD students. How have the results been disseminated to communities of interest?Research outcomes have been presented at international professional conferences, regional industry meetings and field days. We have organized a 2017 CPAAS Agricultural Automation Technology Expo in late July, in which our team have demonstrated the drone imagery technology for agriculture and Solid-set canopy delivery technology for grapevine and tree fruit, and have presented more than 10 research prototypes and about 30 posters for introducing various agricultural automation systems developed and/evaluated under the

umbrella of this project. This one-day event brought over 160 attendees from agri-business industry, specialty crop growers, commodity group representatives, researchers and local media from Pacific Northwest region. Peters gave over 25 different extension education presentations to growers throughout the state, country, and world on irrigation water management and methods to improve irrigation water use efficiency. What do you plan to do during the next reporting period to accomplish the goals?Continue the integrated system research focusing on the feasibility studies of the precision and automation technologies for tree fruit production management.

IMPACT: 2016/10 TO 2017/09
What was accomplished under these goals? Working directly with stakeholders in Washington, this project team has put a great effort on developing automated harvesting solutions for orchards, and focused on developing and testing a pick-and-place robotic harvesting system and a mass shake-and-catch harvesting system for fresh market apple harvest. A new robotic apple-picking end-effector has redesigned based on the dynamics of human hand during manual apple picking and the lessons has learned from field tests of previous design. A modified robotic manipulator is expected to be around 25% cheaper than currently available industrial robotic arms while meeting necessary design specifications to harvest apples and other similar fruit crops. Human-machine collaboration in apple identification have led to identification accuracy of >98% in both day and night time operation. The integrated robotic harvesting system has achieved a harvesting efficiency of 90+% with a harvesting rate of 6 s per apple. Continuing research on targeted shake-and-catch harvester also showed promise for certain variety of apples. For example, both Fuji and Jazz were found to be suitable for targeted mass shake-and-catch harvest as it could achieve an up to 95% removal efficiency with less than 10% bruising damage. As the harvested fruit quality was still not yet satisfactory for fresh market fruit harvest, it did show the promises as the bruising rate was continuously being improved. To provide a systematic robotic solution to apple harvest, our team is continuing the prototype development and validation test of self-propelled bin managing robot to be used in orchards in harvesting. The prototype with four wheel steering system used RTK GPS and laser sensing systems to navigate in orchards. A multi-robot simulation with bin-managing robots and human pickers reduced the time to collect bins in a real-world orchard simulation by up to 30%. Another agricultural robot research focusing area has been on robotic weeding machine for organic vegetable production. We have designed and fabricated a field robot prototype, with field sensing and control devices been integrated and under tuning. This robotic weeding machine, capable of self-leveling the end-effector base for precise control of weed removal point, will be tested and evaluated in commercial WA organic vegetable field in 2018 production season. WSU team also works on sensing and automation technologies with UASs. One specific project we worked on was to use UASs to deter birds from fruit crops such as wine grapes, blueberries and apples. We carried out preliminary field experiments with fixed wing as well as multi- copter UASs this year, which showed some promising results for the effectiveness of this technology in solving this old and important problem in fruit crop production. We are also working on integrating ground and aerial imaging systems to rapidly quantify/evaluate biotic and abiotic stressors in specialty crops. For example, in one of the project related to apple production management to have quality produce without bitter pit disorder, we varied traditional calcium based spray applications frequency and monitored tree physiology and fruit for nutrient deficiencies and its association to bitter pit disorder propagation We have also been evaluating applicability of small-UAS based multi-spectral sensing modules to monitor varied irrigation treatments effect of vine physiology and fruit quality. 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 temporarily in 2018. In 2017 13 different research and demonstration project were done to convert at least one section of a pivot to low energy precision application (LEPA), low elevation spray application (LESA) or mobile drip irrigation (MDI). The growers found these systems to save water (about 17%), save energy (about 20%) and to result in equivalent or improved crop yields. We also worked to refine

methods for estimating crop water stress from remotely taken thermal and multi-spectral images. This work is ongoing.

PUBLICATIONS (not previously reported): 2016/10 TO 2017/09

1. Type: Books Status: Awaiting Publication Year Published: 2017 Citation: 1. Zhang, Q. 2017. Automation in Tree Fruit Production: Principles and Practice. CABI, Oxfordshire, UK, (292 pp)
2. Type: Book Chapters Status: Published Year Published: 2017 Citation: Zhang, Q., Karkee, M. and Khot, L.R. 2017. Mechanization and Automation for Apple Production. In: Evans, K. (ed.) 2017. Achieving Sustainable Cultivation of Apples. Burleigh Dodds, Cambridge, UK.
3. Type: Book Chapters Status: Awaiting Publication Year Published: 2017 Citation: Zhang, Q., Dvorak, J. and Oksanen, T. 2017. Intelligent Machinery for Precision Agriculture. In: Stafford, J. (ed.) 2017. Precision Agriculture for Sustainability. Burleigh Dodds, Cambridge, UK.
4. Type: Book Chapters Status: Awaiting Publication Year Published: 2017 Citation: Zhang, Q. 2017. Tree Fruit Production Automation. In: Zhang, Q. (ed.) 2017. Automation in Tree Fruit Production: Principles and Practice. CABI, Oxfordshire, UK.
5. Type: Book Chapters Status: Awaiting Publication Year Published: 2017 Citation: Rojo, F., Zhang, J., Upadhyaya, S., and Zhang, Q. 2017. Light Interception and Canopy Sensing for Tree Fruit Canopy Management. In: Zhang, Q. (ed.) 2017. Automation in Tree Fruit Production: Principles and Practice. CABI, Oxfordshire, UK.
6. Type: Journal Articles Status: Published Year Published: 2017 Citation: Fu, H., L. He, S. Ma, M. Karkee, D. Chen, Q. Zhang, and S. Wang. 2017. ?Jazz? Apple Impact Bruise Responses to Different Cushioning Materials. Transactions of the ASABE. 60(2): 327-336.
7. Type: Journal Articles Status: Published Year Published: 2017 Citation: He, L., H. Fu, D. Sun, M. Karkee, and Q. Zhang. 2017. Shake and Catch Harvesting for Fresh Market Apples in Trellis Trained Trees. Transactions of the ASABE. 60(2): 353-360.
8. Type: Journal Articles Status: Published Year Published: 2017 Citation: He, L., H. Fu, M. Karkee, and Q. Zhang. 2017. An Effect of fruit location on apple detachment with mechanical shaking. Biosystems Engineering, 157: 63-171.
9. Type: Journal Articles Status: Published Year Published: 2017 Citation: Silwal, A., J. R. Davidson, M. Karkee, C. Mo, Q. Zhang, and K. Lewis. 2017. Design, integration, and field evaluation of a robotic apple harvester. Journal of Field Robotics. 34(6): 1140-1159.
10. Type: Journal Articles Status: Published Year Published: 2017 Citation: Zhou, J., L. R. Khot, R. A. Boydston, P. N. Miklas, and L. Porter. 2017. Low altitude remote sensing technologies for crop stress monitoring: a case study on spatial and temporal monitoring of irrigated pinto bean. Precision Agriculture, DOI: 10.1007/s11119-017-9539.
11. Type: Journal Articles Status: Published Year Published: 2017 Citation: Zuniga, C. E., L. R. Khot, S. Sankaran, and P. Jacoby. 2017. High resolution multispectral and thermal remote sensing-based water stress assessment in subsurface irrigated grapevines. Remote Sensing, 9(9): 961-976.
12. Type: Journal Articles Status: Published Year Published: 2016 Citation: Silwal, A., M. Karkee, and Q. Zhang. 2016. A Hierarchical approach of apple identification for robotic harvesting. Transaction of the ASABE. 59(5): 1079-1086.
13. Type: Journal Articles Status: Published Year Published: 2016 Citation: Zhou, J., L. He, M. Whiting, S. Amatya, P. Larbi, M. Karkee, and Q. Zhang. 2016. Field evaluation of a mechanical-assist cherry harvesting system. Engineering in Agriculture, Environment and Food, 9(4): 324-331.
14. Type: Journal Articles Status: Published Year Published: 2017 Citation: Stout, J.E., J.R. Davenport, and R.T. Peters. 2017. Deficit Irrigation in Vitis labruscana Bailey ?Concord? in Central Washington. Hort Science. 52(3):450-456. doi: 10.21273/HORTSCI11450-16
15. Type: Journal Articles Status: Published Year Published: 2017 Citation: Nakawuka, P., R.T. Peters, and D. Walsh. 2017. Effect of deficit irrigation on yield quantity and quality, water use efficiency and economic returns of four cultivars of hops in the Yakima Valley, Washington State.

Industrial Crops and Products. 98(2017) 82-92. DOI: 10.1016/j.indcrop.2017.01.037
16. Type: Journal Articles Status: Published Year Published: 2017 Citation: Sadeghi, S.H., R.T. Peters, B. Shafii, M.Z. Amini, and C. Stockle. 2017. Continuous Variation of Wind Drift and Evaporation Losses under a Linear Move Irrigation System. Ag. Water Management 182(39-54)

PROGRESS: 2015/10/01 TO 2016/09/30
Target Audience:Specialty crop producers, equipment manufacturers and technology providers who are seeking new solutions to improve crop production and efficiency. Because of the user-centered design nature of this project, outreach to our partners is continuous and integral to its success. The end-users of the technology are included in our initial meetings to identify needed intelligent technologies, and aid in the commercialization of the developed technologies. Modes of project outreach will include expected scientific papers, as well as patents and publications in the trade and popular press. In addition, there will be frequent communication with manufactures, growers and the people who will be using the intelligent system technologies as well as sets of standards used to convey the design concepts learned to a wide audience of engineers and technicians. Changes/Problems: Nothing Reported What opportunities for training and professional development has the project provided?Graduate students (12 total), post-doctoral research associates (5 total), exchange graduate students from foreign insitituES (3 total) and visiting scholars (8 total) working on the project took advantages of opportunities to develop their wide-spectrum of research skills and professionalism in a collaborative working environment. How have the results been disseminated to communities of interest?Research outcomes have been presented at international professional conferences, regional industry meetings and field days. Supplementary to 2015 CPAAS open house event, our team also organized Precision Farming Expo 2016 and IFAC AGRICONTROLS conference 2016 to introduce various research and development activities under this project and to demonstrate various prototype machines being developed. What do you plan to do during the next reporting period to accomplish the goals? Continue the integrated system research focusing on the feasibility studies of the precision and automation technologies for tree fruit production management.

IMPACT: 2015/10/01 TO 2016/09/30
What was accomplished under these goals? Working directly with stakeholders in PNW region, a research strategic plan for developing intelligent solutions for fresh-market apple harvesting was created in 2014. Based on the strategic plan, two mechanical harvesting technologies, one for mass-harvest and another for robotic-harvest, have been studied. Field studies over the last two years have shown that the robotic harvester could harvest about 85% of apples taking about 6 sec to harvest an apple. Shake-and-catch harvesting also showed promise for certain variety of apples. For "Jazz" apples, removal efficiency up to 95% was achieved with about 15% fruit damage. Another research project on finding a robotic solution to assist the harvest process, namely the research for developing an intelligent in-orchard bin-management system also continued in 2016. Another area of our research has been machine vision and end-effector development for automated pruning and training for red raspberry canes. Identification of canes for pruning was investigated with using a Hyperspectral imaging system. This year, two conceptual end-effectors were designed, fabricated and evaluated for bundling and tying the canes together. We also worked on developing a robotic platform for automated weed control in vegetable crops. This year, a self-levelling mechanism for the robotic platform was evaluated in the lab, which showed that the leveling plate of the platform can stay within desirable position and orientation for up to 10 degree roll and pitch angles of outer frame of the platform. A field scale prototype is currently being fabricated for evaluation in 2017. Application of Unmanned Aerial Systems (UAS) for automatically deterring birds has been another component of this project. We evaluated fixed wing and multi-coptor UASs in blueberry and wine grape fields this year. The preliminary results showed that up to 80% reduction in bird activities can be achieved in wine grapes, particularly in the plots with higher

level of bird stress. We are also integrating ground and aerial imaging systems to rapidly quantify/evaluate biotic and abiotic stressors in specialty crops. For example, in one of the project related to apple production management to have quality produce without bitter pit disorder, we varied traditional calcium based spray applications frequency and monitored tree physiology and fruit for nutrient deficiencies and its association to bitter pit disorder propagation. In another sensing project, we are developing technology for rapid sensing of dairy manure nutrients for precision applications in agricultural production. Precision application of manure requires information on its nutrients but the existing reliable nutrient determination methods are unsuitable for real-time applications. This project is evaluating the potential of near infrared spectroscopy for determination of nutrients composition of dairy manure, as a first step towards development of a precision manure application system. We have also been evaluating applicability of small-UAS based multi-spectral sensing modules to monitor varied irrigation treatments effect of vine physiology and fruit quality. 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 temporarily in 2017.

PUBLICATIONS: 2015/10/01 TO 2016/09/30

1. Type: Theses/Dissertations Status: Accepted Year Published: 2016 Citation: Scharf, P. 2016. Optimization of basecutting parameters in laboratory setting to minimize energy requirements for sugarcane harvesting. MS Thesis, Washington State University
2. Type: Theses/Dissertations Status: Accepted Year Published: 2016 Citation: Silwal, A. 2016. Machine Vision System for Robotic Apple Harvesting in Fruiting Wall Orchards. PhD Dissertation, Washington State University
3. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Kafle, G., L. R. Khot*, S. Jarolmasjed, Y. Si and K. Lewis. 2016. Robustness of near infrared spectroscopy based spectral features for non-destructive bitter pit detection in honeycrisp apples. Postharvest Biology and Technology, 120: 180-192.
4. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Zhou, J., L. R. Khot*, T. Peters, M. D. Whiting, Q. Zhang, and D. Granatstein. 2016. Efficacy of unmanned helicopter in rainwater removal from cherry canopies. Computers and Electronics in Agriculture, 124: 161-167.
5. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Kafle, G., L. R. Khot, J. Zhou, H. Y. Bahlol and Y. Si. 2016. Towards precision spray applications to prevent rain-induced sweet cherry cracking: understanding calcium washout due to rain and fruit cracking susceptibility. Scientia Horticulturae, 203: 152-157.
6. Type: Book Chapters Status: Accepted Year Published: 2016 Citation: He, L., J. Zhou, Q. Zhang, and H.J. Charvet, 2016. A string twining robot for high trellis hop production. Computers and Electronics in Agriculture, 121: 207-214.
7. Type: Book Chapters Status: Accepted Year Published: 2016 Citation: Osroosh, Y., R.T. Peters, C.S. Campbell, and Q. Zhang. 2016. Comparison of irrigation automation algorithms for drip-irrigated apple trees. Computers and Electronics in Agriculture, 128: 87-99.
8. Type: Book Chapters Status: Accepted Year Published: 2016 Citation: Zhang, J., Q. Zhang, and M.D. Whiting, 2016. Canopy light interception conversion in upright fruiting offshoot (UFO) sweet cherry orchard. Transactions of the ASABE, 59(4): 727-736.
9. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Kafle, G., L. R. Khot, S. Sankaran, H. Y. Bahlol, J. A. Tufariello, and H. H. Hill Jr. 2016. State of ion mobility spectrometry and applications in agriculture: A review. Engineering in Agriculture, Environment and Food, 9(4): 346-357.
10. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Jarolmasjed, S., C. L. Zuniga, S. Sankaran, and L. R. Khot. 2016. Postharvest bitter pit detection and progression evaluation in 'Honeycrisp' apples using computed tomography images. Postharvest Biology and Technology, 118: 35-42.

11. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Khot, L. R., S. Sankaran, A. H. Carter, D. A. Johnson, and T. F. Cummings. 2016. UAS imaging based decision tools for arid winter wheat and irrigated potato production management. International Journal of Remote Sensing, 37(1): 125-137.
12. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Zhou, J., L. He, M. Whiting, S. Amatya, P. Larbi, M. Karkee, and Q. Zhang. 2016. Field evaluation of a mechanical-assist cherry harvesting system. Engineering in Agriculture, Environment and Food, 9(4): 324-331.
13. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Silwal, A., M. Karkee, and Q. Zhang. 2016. A Hierarchical approach of apple identification for robotic harvesting. Transaction of the ASABE. 59(5): 1079-1086.
14. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Santiago, W. E., N. J. Leite, B. J. Teruel, M. Karkee, C. A. M. Azania, and R. Vitorino. 2016. Development and testing of image processing algorithm to estimate weed infestation level in corn fields. Australian Journal of Crop Science.
15. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Davidson, J., A. Silwal, M. Karkee, C. Mo, and Q. Zhang. 2016. Hand picking dynamic analysis for undersensed robotic apple harvesting. Transactions and the ASABE, Vol. 59(4): 745-758.
16. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Li, J., M. Karkee, Q. Zhang, K. Xiao, and T. Feng. 2016. Characterizing apple fruit robotic picking patterns and detaching parameters. Computers and Electronics in Agriculture, 127:633-640.
17. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Ma, S., P. A. Scharf, Q. Zhang, M. Karkee, J. Tong, and L. Yu. 2016. Effect of cane stool density and stubble height on sugarcane stubble damage in Hawaii fields. Transactions and the ASABE, 59(3): 813-820.
18. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Amatya, S., and M. Karkee, 2016. Integration of visible branch sections and cherry clusters for detecting cherry tree branches in dense foliage canopies. 2016. Biosystems Engineering, 119:72-81.
19. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Zhou, J., L. He, M. Karkee, and Q. Zhang. 2016. Analysis of shaking-induced cherry fruit motion and damage. Biosystems Engineering, 144: 105-114.
20. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Zhou, J., L. He, M. Karkee, and Q. Zhang. 2016. Effect of catching surface and tilt angle on reducing of bruise damage of sweet cherry due to mechanical impact. Computers and Electronics in Agriculture, 121:282-289.
21. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Amatya, S., M. Karkee, A. Gongal, Q. Zhang, M.D. Whiting. 2016. Detection of cherry tree branches in planner architecture for automated sweet-cherry harvesting. Biosystems Engineering. 146:3-15.
22. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: De Kleine, M. E., and M. Karkee. 2016. A semi-automated harvesting prototype for shaking fruit tree limbs. Transactions of the ASABE, 58(6): 1461-1470.
23. Type: Journal Articles Status: Accepted Year Published: 2016 Citation: Gongal, A., A. Silwal, S. Amatya, M. Karkee, Q. Zhang, and K. Lewis. 2016. Apple crop-load estimation with over-the-row machine vision system. Computers and Electronics in Agriculture, 20: 26?35
24. Type: Theses/Dissertations Status: Accepted Year Published: 2016 Citation: Ye, Y., 2016. A maneuverability study on a wheeled bin management robot in tree fruit orchard environments. Ph.D. Dissertation, April 2016, Washington State University.

PROGRESS: 2015/03/01 TO 2015/09/30

Target Audience:Specialty crop producers, equipment manufacturers and technology providers who are seeking new solutions to improve crop production and efficiency. Because of the user-centered design nature of this project, outreach to our partners is continuous and integral to its success. The end-users of the technology are included in our initial meetings to identify needed intelligent technologies, and aid in the commercialization of the developed technologies. Modes of project outreach will include expected scientific papers, as well as patents and publications in the trade and popular press. In addition, there will be frequent communication with manufactures, growers and the people who will be using the intelligent system technologies as well as sets of standards used to convey the design concepts learned to a wide audience of engineers and technicians. Changes/Problems:Team has additional member, Dr. Lav Khot, as part of this project starting 2015 year with research and extension emphasis on remote and proximal sensing based decision support tools and technologies development for real-time crop production management. What opportunities for training and professional development has the project provided?Graduate students (3 for Khot, 4 for Dr. Karkee; 2 for Dr. Zhang) and post-doctoral research associates (2 for khot, 2 for Drs. Karkee and Zhang) working on the project took advantages of opportunities to develop their wide-spectrum of research skills and professionalism in a collaborative working environment. How have the results been disseminated to communities of interest?Research outcomes have been presented at international professional conferences, regional industry meetings and field days. We also organized a CPAAS open house event to introduce various research and development activities under this project and to demonstrate various prototype machines being developed. What do you plan to do during the next reporting period to accomplish the goals?Continue the integrated system research focusing on the feasibility studies of the precision and automation technologies for tree fruit production management.

IMPACT: 2015/03/01 TO 2015/09/30
What was accomplished under these goals? Working directly with stakeholders in PNW region, a research strategic plan for developing intelligent solutions for fresh-market apple harvesting was created in 2014. Based on the goals and objectives defined in the strategic plan, two conceptual technologies, one for mass-harvest and another for robotic-harvest, have been developed and were studied. Preliminary field studies showed that the robotic harvester would be able to harvest about 85% of apples taking about 6 sec to harvest each apple. Shake-and-catch harvesting method also showed promise for certain variety of apples. For 'Jazz' apples, removal efficiency up to 98% was achieved with about 15% fruit damage. Another research project on finding a robotic solution to assist the harvest process, namely the research for developing an intelligent in-orchard bin-management system also continued in 2015. All these research projects aim to prove the concept of intelligent solutions for more effectively and efficiently harvest of fresh-market apples. We have also been developing and evaluating mechanical harvesting systems suitable for harvesting sweet cherry from multiple canopy systems. This year, we developed a machine vision system to automate shake-and-catch cherry harvesting machine. Image processing of cherry trees trained in Upright Fruiting Offshoot (UFO) architecture has shown an accuracy of >85% in identifying branches for shaking. We also conducted baseline test of using existing commercial sugarcane harvester for biofuel feedstock, such as energy-cane, to assess the feasibility and issues need to be addressed regarding use of existing machinery in biofuel feedstock production. Another area of our research has been machine vision and end-effector development for automated pruning and training for red raspberry canes. Identification of canes for pruning was investigated with using a Hyperspectral imaging system. Several conceptual end-effectors were designed for bundling the canes together, and one prototype machine was fabricated and evaluated in the field in 2015. Developed and demonstrated a mobile system, which measures the interception of photosynthetically active radiation (PAR) for orchards with modern fruiting wall canopy systems. This measurement system was able to maintain a constant spatial resolution 0.01 × 0.10 m within a moving speed varying range of 0-3.8 km per hour, and to automatically correct data distortion caused by different time and different location of the measurement being made. Remote and proximal sensing based decision support tools/technologies for real-time crop production management has been another focus area that was added to scope of this project. One of such project focused on development of in-field sensing based decision support system to prevent sweet cherry fruit cracking due to rainwater. An in-field sensing system was developed to monitor canopy

wetness and micro-climate during and after rainfalls, which will help growers to decide upon when and how much rainwater needs to be removed from canopies. The in-field sensing was then used to evaluate the efficacy of an unmanned middle-size helicopter (emerging technology) to remove rainwater from cherry canopies trained to a Y-trellised architecture. The developed sensing system was also used to evaluate the efficacy of an orchard air-blast sprayer in rainwater removal in orchards with Y-trellised architecture (two varieties: Skeena and Selah) and vertical architecture (Selah). We are also integrating ground and aerial imaging systems to rapidly quantify/evaluate biotic and abiotic stressors in specialty crops. For example, in one of the project related to apple production management to have quality produce without bitter pit disorder, we varied traditional calcium based spray applications frequency and monitored tree physiology and fruit for nutrient deficiencies and its association to bitter pit disorder propagation. Similarly, we are evaluating applicability of ground small-UAS based multi-spectral sensing modules to monitor varied irrigation treatments effect of vine physiology and fruit quality. We also evaluated the UAS-based imagery for rapid assessment potato crop necrosis to substitute subjective approaches followed by researchers and growers to observe improved soil health due to crop rotations and manure amendments.

PUBLICATIONS: 2015/03/01 TO 2015/09/30

1. Type: Journal Articles Status: Published Year Published: 2015 Citation: He, L., J. Zhou, Q. Zhang, M. Karkee. 2015. Evaluation of multipass mechanical harvesting on ?Skeena? sweet cherries trained to Y-trellis. HortScience, 50(8): 1178-1182.
2. Type: Books Status: Published Year Published: 2015 Citation: Zhang, Q. 2015. Precision Agriculture Technology for Crop Farming. CRC Press, Boca Raton, FL, (360 pp).
3. Type: Book Chapters Status: Published Year Published: 2015 Citation: Zhang, Q. 2015. Control of Precision Agriculture Production. In: Zhang, Q. (ed.) 2015. Precision Agriculture Technology for Crop Farming. CRC Press, Boca Raton, FL.
4. Type: Journal Articles Status: Published Year Published: 2015 Citation: Sankaran, S., Khot, L.R., and Carter, A.H. 2015. Field-based crop phenotyping: multispectral aerial imaging for evaluation of winter wheat emergence and spring stand, Computers and Electronics in Agriculture, 118: 372-379.
5. Type: Journal Articles Status: Published Year Published: 2015 Citation: Ma, S., P. A. Scharf, M. Karkee, and Q. Zhang. 2015. Performance Evaluation of a Chopper Harvester in Hawaii Sugarcane Fields. The Transactions of ASABE, 58(2): 271-279.
6. Type: Journal Articles Status: Published Year Published: 2015 Citation: Gongal, A., S. Amatya, M. Karkee, Q. Zhang, and K. Lewis. 2015. Sensors and Systems for Fruit Detection and Localization: A Review. Computers and Electronics in Agriculture, 116:8-19.
7. Type: Journal Articles Status: Published Year Published: 2015 Citation: Larbi P., S. Amatya, M. Karkee, Q. Zhang, and M. Whiting. 2015. Modification and Field Evaluation of an Experimental Mechanical Sweet Cherry Harvester. Applied Engineering in Agriculture, 31(3):387-397.
8. Type: Journal Articles Status: Published Year Published: 2015 Citation: Larbi, P., C. N Vong, M. Karkee. 2015. A Study of Operator Performance for a Mechanical Sweet Cherry Harvester: Comparison between Manual and Remote-Controlled Operation. Journal of Agricultural Safety and Health, 21(3): 145-157.
9. Type: Journal Articles Status: Published Year Published: 2015 Citation: De Kleine, M.E., and M. Karkee. 2015. Evaluating a non-Newtonian Shear Thickening Surface During Fruit Impacts. The Transactions of ASABE, 58(3): 907-915.
10. Type: Journal Articles Status: Published Year Published: 2015 Citation: Karkee, M., and B. Adhikari. 2015. A Method for Three Dimensional Reconstruction of Apple Trees for Automated Pruning. Transactions of the ASABE, 58(3): 565-574.
11. Type: Journal Articles Status: Published Year Published: 2015 Citation: Sharda, A., M. Karkee, Q. Zhang, J. Brunner, I. Ewlanow, and U. Adameit. 2015. Effect of emitter type and mounting configuration on spray coverage for Solid Set Canopy Delivery Systems. Computers and Electronics in Agriculture, 112: 184-192.

12. Type: Journal Articles Status: Published Year Published: 2015 Citation: Zhang, J., M.D. Whiting, and Q. Zhang. 2015. Diurnal pattern in canopy light interception for tree fruit orchard trained to an upright fruiting offshoots (UFO) architecture. Biosystems Engineering, 129(1): 1-10.
13. Type: Journal Articles Status: Published Year Published: 2015 Citation: Zhang, J., Q. Zhang, and M. D. Whiting, 2015. Mapping interception of photosynthetically active radiation in sweet cherry orchards. Computers and Electronics in Agriculture, 111: 29-37.
14. Type: Journal Articles Status: Published Year Published: 2015 Citation: Osroosh, Y., R.T. Peters, C.S. Campbell and Q. Zhang, 2015. Automatic irrigation scheduling of apple trees using theoretical crop water stress index with an innovative dynamic threshold. Computers and Electronics in Agriculture, 118: 193-203.
