Arizona

Participant: Mark Siemens, University of Arizona

Accomplishments

During 2014, an automated machine for thinning lettuce developed at the University of Arizona was further developed so that it could thin unwanted plants and spot apply insecticides to saved crop plants in the same pass. Trials were conducted to determine whether spot spraying individual crop plants was as effective as conventional banding or broadcast application methods. Results showed no significant differences between treatments. As compared to broadcast spraying, spot spraying reduces pesticide application rates by over 90% and thereby, depending on the chemical applied, provides significant savings to growers (typically about $23 per acre). An additional benefit is that environmental risks are significantly reduced.

The automated thinning machine was also modified so that it could be used as an intra-row and inter-row weeding machine. Study results in lettuce showed that although weed control was inferior hand weeding, in fields where weed pressure was high, automated weeding followed by hand weeding significantly reduced overall labor requirements. In such cases, utilization of the automated weeding system developed herein may be economically viable and help ease the industry's labor shortage problems.

Impact

Developed new knowledge and technologies for thinning, spot spraying and weeding lettuce with automated machines.

Publications

Fennimore, S.A., B. D. Hanson, L. M. Sosnoskie, J. B. Samtani, A. Datta, S. Z. Knezevic, and M. C. Siemens. 2013. Chapter 9: Field Applications of Automated Weed Control: Western Hemisphere. In Automation: The Future of Weed Control in Cropping Systems, 151-169. S.L. Young and F.J. Pierce, eds. Dordrecht: Springer Science+Business Media.

Siemens, M.C. Robotic weed control. 2014. In Proc. *66th Annual California Weed Science Society* 66: 76-80. Salinas, Calif.: California Weed Science Society.

California

Participants: David Slaughter, Stavros Vougioukas, Michael Delwiche, Dept. of Biological & Agricultural Engineering, University of California, Davis

Accomplishments:

- **Short-term Outcomes**:
  - 3D spatial location data for more than 10,000 fruits (pears and clingstone peaches) while on the tree; helped growers verify the effectiveness of their pruning and thinning strategies.
  - Design of an optical flow cell and automated maturity measurement system using color for use in official inspection by the California Processing Tomato Inspection Program. Provides tomato growers and processors with new tools needed for precise and unbiased assessment of tomatoes at harvest to facilitate accurate determination of market value.
- **Outputs**:
  - 3D fruit mapping progress reports were submitted to the California Pear Advisory Board and to the California Canning Peach Mechanization Research Fund. The 3D fruit mapping results were presented at three grower meetings organized by the University of California ANR Extension Advisors.
  - Progress report on tomato color and maturity system design and performance was submitted to the California Processing Tomato Advisory Board (PTAB). Two presentations were made to tomato growers and processors at PTAB committee and board meetings.
- **Activities**:
  - Fruit location data and tree branch geometries were analyzed. The statistics provided improved understanding of the fruit distributions and branching patterns of orchard pear and cling-peach trees.
  - Prototype tomato color measurement systems were designed, fabricated and tested at official inspection stations operated by the California Processing Tomato Advisory Board. Data from actual truckloads of processing tomato was collected and analyzed to determine new knowledge about tomato optical properties, and assess accuracy, precision and inter-instrument agreement.
- **Milestones**:
  - Completion of tree digitization platform – February 2014.
  - Development of a 2nd generation automated system for determination of maturity measurement system using color for use in official inspection by the California Processing Tomato Inspection Program - July 2014.

Impacts:

The geo-referenced location data of fruits in tree canopies and the tree branch geometries will be used to perform model-based machine design for tree fruit mechanized harvesting. The potential impact is reduced dependence on manual labor for fresh market fruit harvest.

The development of an accurate, automated system for determination of color and maturity in processing tomato will directly impact tomato growers and processors by providing a cost-effective and accurate system of characterizing the stage of development and subsequent quality of the harvested fruit. Well mature tomato fruit have superior flavor and lycopene content. By ensuring that harvested tomatoes are mature, the health benefits of adding lycopene to the diet and the pleasure of consuming flavorful food can be delivered to consumers in the final processed tomato product.

Grants received as a result of project activities:
Grant Title: A Rapid Prototyping Design Tool For Pear Harvest Mechanization.

PI: Stavros Vougioukas; Co-PI: David Slaughter
Funding sources: California Pear Advisory Board
Grant award: $27,458.00. Award term: 4/12/2014 – 6/30/2015

Grant Title: A Rapid Prototyping Design Tool For Cling-Peach Harvest Mechanization.
PI: Stavros Vougioukas; Co-PI: David Slaughter
Funding sources: Canning Peach Mechanization Research Fund
Grant award: $27,458.00. Award term: 6/1/2014 – 5/30/2015

Grant Title: Automated Inspection Systems for Processing Tomatoes
PI: David Slaughter
Funding source: California Processing Tomato Advisory Board
Grant award: $124,971, Award term: 2/1/2014 - 1/31/2015.

Publications:

Arikapudi, R., Durand-Petiteville, A., Vougioukas, S. (2014). Model-based assessment of robotic fruit harvesting cycle times. ASABE Annual Intl. Meeting; Paper Number 1913999, Montreal, Quebec, Canada.

Farangis Khosro, A., Rehal, R., Fathallah, F., Wilken, K., Vougioukas, S. (2014). Sensor-based Stooped Work Monitoring in Robot-aided Strawberry Harvesting. ASABE Annual Intl. Meeting; Paper Number 1913911, Montreal, Quebec, Canada.

Wei-jiunn, J., Lewis, G., Hoachuck, J., Slaughter, D., Wilken, K., Vougioukas, S. (2014). Vibration-reducing Path Tracking Control for a Strawberry Transport Robot. ASABE Annual Intl. Meeting; Paper Number 1914011, Montreal, Quebec, Canada.

He, L., Arikapudi, R., Khosro Anjom, F., Vougioukas, S. (2014). Worker Position Tracking for Safe Navigation of Autonomous Orchard Vehicles Using Active Ranging. ASABE Annual Intl. Meeting; Paper Number 141913710, Montreal, Quebec, Canada.

Slaughter, D.C., (2014). Standardization and Automation in Official Maturity Grading of Processing Tomato. ASABE Annual Intl. Meeting; Paper Number 1900557, Montreal, Quebec, Canada.

Florida

Participants: Reza Ehsani, Won Suk Lee. University of Florida.

Accomplishments

- A collaborative research project conducted at the University of Central Florida and citrus research and education center of the University of Florida **with goal of reducing scouting costs and crop loss due to various stress factors**. The specific goal was to develop a robust ground and aerial crop health monitoring system that could detect and map crop stress in citrus and strawberry production system as an example of a tree and a vegetable production system. The following activities were pursued:

(1) Developed an innovative ground based robotic system with autonomous capabilities to help monitor and analyze a strawberry field for diseases in close-proximity by **taking spectral imaging** and collecting leaf samples throughout the field.
(2) Developed **an octocopter to** help monitor and analyze a strawberry field rapidly and relay the suspected area coordinates to the **ground robot**.
(3) Developed the first **version of disease detection sensor**, which could be applied on both the aerial- and ground-based platforms.
(4) Disseminated research results to a broader range of audience.

- A novel technique was developed to **detect immature green citrus** in tree canopy under natural outdoor conditions. Shape analysis, texture classification, SVM, graph based connected component algorithm, and Hough line detection were used to identify fruit and to remove false positives. Keypoints by scale invariant feature transform algorithm were used to further remove false positives. The algorithm was able to detect and count 80% of citrus fruit for validation. This method was published in the Biosystems Engineering. An algorithm for detecting immature peach fruit on the tree was also developed and was published in the Precision Agriculture journal. Hyperspectral images of blueberry fruit were taken in a commercial blueberry field. Mature fruit, intermediate fruit, young fruit and background were the four classes to be studied. A supervised band selection method was proposed using Kullback-Leibler divergence (KLD). Based on the analysis, six combined bands were selected. The test result showed that the proposed band selection method worked well for the task of blueberry growth stages detection.

- Using polarized filter and narrow band imaging technique, **a portable machine vision system was developed to detect the citrus greening symptomatic leaves**. This study yielded detection rates of over 90%. Different dimension reduction methods were investigated to detect the citrus greening disease using airborne hyperspectral imaging. These methods yielded detection accuracies of 63-93%. A novel detection method, ‘extended spectral angle mapping (ESAM)’ was developed to detect citrus greening disease using Savitzky-Golay smoothing filter, SVM and vertex component analysis. A high detection accuracy of 86% was achieved for validation. Also satellite images were used to detect citrus greening disease over large areas from a Landsat 5 Thematic Mapper (TM) and a WorldView-2 images. It was demonstrated that there is a great potential for citrus greening disease detection using a satellite image.

- Another machine vision system was developed to **detect dropped citrus fruit on the ground** along with a GPS receiver. It can count the number of fruit and estimate mass of the fruit with an accuracy of 89%.

- A prototype laser weeding system was developed to kill in-row weeds using machine vision and a set of lasers to demonstrate the concept. This work was presented at the 5th Asian Conference on Precision

Agriculture. An automated in-row weed control system was being tested, consisting of an ultrasonic sensor and a pair of pinch rollers. A preliminary field test results showed that the mechanical weeding machine were able to uproot weeds. Weeds height was ranged from 10 cm to 18 cm. Further field experiments will be conducted to evaluate the efficacy of the intra-row weeding prototype and crop injury.

- Equilibrium moisture content (EMC) for triticale seed was investigated. A prediction algorithm was developed to represent the relationship between relative humidity and EMC with coefficient of determination (R^2) equal to 0.99. It was also found that the Modified Henderson equation represents this relationship accurately. A method was developed to determine the degrees of infestation (DI) in the triticale seed at two growth stages by measuring their spectral reflectance. The reflectance was measured from 400 nm to 2500 nm. The result showed that the DI for larvae 2nd instar stage could be detected using an average reflectance in 400 - 410 nm, with an R^2 of 0.87. The adult outside stage also resulted in a good prediction, where it yielded four wavelengths that provided an acceptable result with an R^2 of 0.87 for the adult outside stage.

Publications

Bansal, R., W. S. Lee, and S. Satish. 2013. Green citrus detection using Fast Fourier Transform (FFT) leakage. Precision Agriculture 14(1): 59-70. http://dx.doi.org/10.1007/s11119-012-9292-3.

Aksenov, A. A., A. Pasamontes, D. J. Peirano, W. Zhao, A.M. Dandekar, O. Fiehn, R. Ehsani and C. Davis. 2014. Detection of Huanglongbing Disease Using Differential Mobility Spectrometry. Analytical Chemistry. 86(5):2481-2488.

Choi, D., W. S. Lee, R. Ehsani, and A. Banerjee. 2013. Detecting and counting citrus fruit on the ground using machine vision. ASABE Paper No. 131591603. St. Joseph, Mich.: ASABE.

Garcia-Ruiz, F., S. Sankaran, J. M. Maja, W. S. Lee, J. Rasmussen, and R. Ehsani. 2013. Comparison of two aerial imaging platforms for identification of Huanglongbing infected citrus trees. Computers and Electronics in Agriculture 91: 106-115. http://dx.doi.org/10.1016/j.compag.2012.12.002

Jadhav, U., L. R. Khot, R. Ehsani, V. Jagdale, J. K. Schueller. 2014. Volumetric mass flow sensor for citrus mechanical harvesting machines. Computers and Electronics in Agriculture. 101: 93-101.

Katti, A. R., W. S. Lee, and C. Yang. 2013. Laser weeding system for elimination of in-row weeds. In Proceedings of the 5th Asian Conference on Precision Agriculture (ACPA), June 25-28, 2013, Jeju, Korea.

Khedher Agha, M. K., W. S. Lee, C. Wang, R. W. Mankin, N. Bliznyuk, and R. A. Bucklin. 2013. Determination degrees of insect infestation in triticale seed using NIR spectroscopy. ASABE Paper No. 131592957. St. Joseph, Mich.: ASABE.

Khedher Agha, M. K., W. S. Lee, R. A. Bucklin, A. A. Teixeira, and A. Blount. 2013. Equilibrium moisture content equation for triticale seed. ASABE Paper No. 131620333. St. Joseph, Mich.: ASABE.

Lee, W. S. 2013. Book review: N. Kondo, M. Monta, and N. Noguchi, Agricultural robots - mechanisms and practice, Corona Publishing Co., Ltd. Tokyo, Japan, 2011, xii + 348 pp., ISBN: 978-4-87698-553-1. Journal of Biosystems Engineering 38(2): i.

Li, H., W. S. Lee, and K. Wang. 2013. Airborne hyperspectral imaging based citrus greening disease detection using different dimension reduction methods. ASABE Paper No. 131592802. St. Joseph, Mich.: ASABE.

Li, H., W. S. Lee, and K. Wang. 2013. Spectral mixture analysis based citrus greening disease detection using satellite image of Florida. In Proceedings of the 5th Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS). 25-28 June 2013, Gainesville, Florida, USA.

Li, H., W. S. Lee, K. Wang, R. Ehsani, and C. Yang. 2013. 'Extended spectral angle mapping (ESAM)' for citrus greening disease detection using airborne hyperspectral imaging. Precision Agriculture. http://dx.doi.org/10.1007/s11119-013-9325-6.

Li. H, W. S. Lee, K. Wang, R. Ehsani, and C. Yang. 2014. Extended spectral angle mapping (ESAM) for citrus greening disease detection using airborne hyperspectral imaging. Precision Agriculture 15:162-183

Liaghat, S. *, Ehsani, R., Mansor, S.B., Shafri, H.Z.M., Meon, S., Azam, S.H.M.N. and Noh, N.M.2014. Early detection of basal stem rot disease (Ganoderma) in oil palms based on hyperspectral reflectance data using pattern recognition algorithms. International Journal of Remote Sensing, 35:10, 3427-3439.

Liaghat, S., S. Mansor, R. Ehsani, H.Z.M. Shafri, S. Meon and S. Sankaran. 2014. Mid-infrared spectroscopy for early detection of basal stem rot disease in oil palm. Computers and Electronics in Agriculture 101: 48-54.

Pourreza, A., W. S. Lee, E. Raveh, R. Ehsani, and E. Etxeberri. 2014. Citrus greening disease detection using narrow band imaging and polarized illumination. Transactions of the ASABE. 57(1): 259-272.

Pourreza, A., W. S. Lee, E. Raveh, Y. K. Hong, and H. J. Kim. 2013. Identification of citrus greening disease using a visible band image analysis. ASABE Paper No. 131591910. St. Joseph, Mich.: ASABE.

Saber, M., W. S. Lee, T. F. Burks, G. E. MacDonald, and G. Salvador. 2013.An automated mechanical weed control system for organic row crop production. ASABE Paper No. 131593595. St. Joseph, Mich.: ASABE.

Yang, C., W. S. Lee, and P. Gader. 2013. Band selection of hyperspectral imagery for the classification of blueberry fruit maturity stages and leaf. ASABE Paper No. 131593276. St. Joseph, Mich.: ASABE.

Yang, C., W. S. Lee, P. Gader, and H. Li. 2013. Hyperspectral band selection using Kullback-Leibler divergence for blueberry fruit detection. In Proceedings of the 5th Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing (WHISPERS). 25-28 June 2013, Gainesville, Florida, USA.

Georgia

Participants: Changying Li, Chi Thai, Bill Tollner, College of Engineering, University of Georgia

Accomplishments:

- A multimodal machine vision system was developed for quality inspection of onions. The system integrates hyperspectral, color, 3D, and X-ray imaging technologies to evaluate multiple onion quality properties nondestructively. A LabVIEW program was developed to acquire color image, NIR spectral image, depth image, and X-ray images of onions, and measure the weight of onions. Data fusion algorithms based on image processing, statistical, and machine learning techniques were applied to accurately estimate the maximum diameter (RMSE=1.7 mm), volume (accuracy=96.9%), and density of onions (RMSE=0.03 gram/cm^3).
- The multimodal machine vision system was also able to detect defective onions more effectively than using a single sensor. Three types of onions were tested in this study: healthy onions without inoculation, inoculated with *Burkholderia cepacia*, and inoculated with *Pseudomonas viridiflava*. Using image features selected from onion X-ray and spectral images, the classification tree utilizing features combined at the feature level distinguished 84.21% onions, compared to 78.95% and lower using single sensor/camera.
- Transportation of blueberries from field to the packing house was evaluated using an accelerometer and data logger. The results showed that the uneven road and fast speed of the tractor could generate large vibrations and consequently cause potential bruises to the fruit.
- Blueberry packing lines were evaluated using Berry Impact Recording Device (BIRD). Six replicates were tested through the packing line before and after five transition points were padded using Poron padding sheet and impacts were recorded at the transition points. The biggest impacts occurred at the beginning and end of the line. The impact level was reduced significantly at these transition points after padding. The maximum impact was reduced by 57%, 59%, 47% and 54% at the first four padded transition points after being padded.

Impact:

- The multisensor-based system can evaluate both external and internal quality parameters of onions, and provided a base for the further development of fully automated robotic system for onion quality inspection. The system and methods developed from this project are also potentially applicable to quality inspection of other agricultural products.

Publications:

Jiang, Yu and C. Li. A Push-broom based Hyperspectral Imaging System for Cotton Trash Identification. ASABE Paper No: 141898244. Montreal, Quebec Canada. July 13-16, 2014.

Li, C., P. Yu, F. Takeda, G. Krewer. 2013. A miniature instrumented sphere to understand impacts created by mechanical blueberry harvesters. HortTechnology. 23(4): 425-429.

Takeda, F., G. Krewer, C. Li, D. MacLean, and J. W. Olmstead. 2013. Techniques for increasing machine-harvest efficiency in southern highbush and rabbiteye blueberries. HortTechnology. 23(4): 430-436.

Wang, W. and C. Li. 2014. Size estimation of sweet onions using consumer-grade RGB-depth sensor. Food Engineering. 142: 153–162.

Wang, Weilin and C. Li. A multimodal quality inspection system based on 3D, hyperspectral, and X-ray imaging for onions. ASABE Paper No: 141900673. Montreal, Quebec Canada. July 13-16, 2014.

Wang, Weilin. A multiple sensor system for quality inspection of onions and investigation of onion optical properties. Ph.D. Dissertation. University of Georgia. December, 2014. Athens, Georgia.

Xu, Rui, Changying Li, Fumiomi Takeda, and Gerard Krewer. Measuring Impacts of Blueberries during Transportation and Packing. ASABE Paper No: 141898243. Montreal, Quebec Canada. July 13-16, 2014.

Yu, P., C. Li*, F. Takeda and G. Krewer. 2014. Visual bruise assessment and analysis of mechanical impact measurement in southern highbush blueberry. Applied Engineering in Agriculture. 30(1): 29-37.

Yu, P., C. Li*, F. Takeda, G. Krewer, G. Rains, and T. Hamrita. 2014. Evaluation of rotary, slapper, and sway blueberry mechanical harvesters for potential fruit impact points using a miniature instrumented sphere. Comput. Electron. Agr. 101:84–92.

Hawaii

Accomplishments:

Reconfigu**red green bean coffee heat treatment facility** from in and out same side to slide through.

Initiated a burial experiment to determine soil moisture, depth, and *Bassiana beauvaria* inoculation to control *H. hampei*. Will use data to design a furrow system for mechanized coffee producers.

Impacts:
The low operating cost – approx. $20 per lot – will encourage compliance with the coffee berry borer (CBB) quarantine of Hawaii County. Compliance should delay, if not prevent, the movement of CBB coffee farms on the other islands of the State of Hawaii. Savings and increased markets will be experienced for Hawaii County coffee producers shipping to the high population and high tourist activity islands of Oahu and Maui.

Publications:
None

Iowa

Participants: Drs. Matthew Darr, Mark Hanna, Brian L. Steward, Lie Tang, Iowa State University.

Accomplishments:

Robotic non-chemical weeding: A new set of plant detection algorithms based on 3D point cloud data analysis. A new generation prototype of an automated **intra-row mechanical weeder** is under development. The design was further refined our dual pivoting arm mechanism with both electric and pneumatic activation. A life cycle energy analysis was performed on different weed control methods to compare conventional methods with a robotic mechanical weeder. The power required for a prototype weeding mechanism was measured experimentally as a function of depth, rotational speed and forward ground speed. The robotic weeder was shown to require substantially lower energy than conventional methods.

High-throughput plant phenotyping using robotic technologies: A robotic vehicle that is equipped **with auto-steer system** and a rig **of six stereo camera** heads has been developed. Stereo vision algorithms that incorporate both local and global approaches have been developed to overcome the textureless and high-degree of curvature of plant leaf surfaces. A new sensor apparatus for high-throughput plant stand analysis

Cucurbit mechanized row cover establishment: Results from summer 2013 to evaluate operation of single-row cover establishment were analyzed and a technical paper was written. A senior design project investigated alternative methods to feed and insert wire on an existing implement. Summer 2014 field work is investigating durability of a multi-row system including support structure and cover material.

Impacts:

Automated non-chemical weeding: Results show that it may be possible to achieve good weed control efficacy mechanically at substantially lower power levels than previously considered. Such technology has potential for broad impact as it opens the way to the development of smaller autonomous, mechanical weeding systems. Small robotic weeding system for specialty crops may substantially lower energy costs for producers.

High-throughput plant phenotyping using robotic technologies: Applying robotic technologies can overcome the bottleneck problem of large scale phenotypic data collection.

Cucurbit mechanized row cover establishment: Short video reports of project work are posted on a web site for growers to view. A method to automate feeding of support wires received third place nationally in student senior design competition for the American Society of Agricultural and Biological Engineers.

Publications:

Patent Disclosure:

Lie Tang, Ji Li, Yin Bao, Jian Jin, Akash Dev Nakarmi. US 62/006,301. Title: Crop stand analyzer using reflective laser proximity sensors. June, 2014.

Book Chapters

Taufik Ahmad, M., L. Tang, B. Steward. 2013. Chapter 7: Automated Mechanical Weeding. Automation: The Future of Weed Control in Cropping Systems. S. L. Young and F. J. Pierce (eds). Springer. P 125 – 138.

Referred Journal Papers:

Nakarmi, A. D. and L. Tang. 2014. Within-Row spacing sensing of maize plants using 3D computer vision. Biosystems Enngineering PP. 54-64 DOI Information: 10.1016/j.biosystemseng.2014.07.001

Conference Papers:

Hanna, H. M., B. L. Steward, and K. A. Rosentrater. 2014. Evaluation of mechanized row cover establishment for cantaloupe and summer squash. ASABE Paper No. 141894433. St. Joseph, Mich.: ASABE.

Bao, Y., A. D. Nakarmi, L. Tang. 2014. Develoomento of a filed phenotyping robotic system for sorghum biomass yield component traits characterization. ASABE Paper No. 141901199, St. Joseph, MI: ASABE.

Toledo, O. M., B. L. Steward, L. Tang, and J. Gai. 2014. Techno-economic analysis of future precision field robots. ASABE Paper No. 141903313. St. Joseph, Mich.: ASABE.

Tu, X. Y. and L. Tang. 2013. Robust Navigation Control of an Autonomous Agricultural Robotic Vehicle. ASABE Paper No. 131620548, St. Joseph, MI: ASABE.

Li, J. and L. Tang. 2013. Real-time Plant Recognition for Robotic Weeding Using a 3D ToF Sensor. ASABE Paper No. 131620787, St. Joseph, MI: ASABE.

Li, J. and L. Tang. 2013. Machine Vision-based Indirect Estimation of the Position and Attitude of Mobile Robots. ASABE Paper No. 131620769, St. Joseph, MI: ASABE.

Kentucky

Participant: Dvorak, Joe. University of Kentucky.

Accomplishments:

Testing of a series hybrid drivetrain for agricultural machinery was completed. The drivetrain was constructed using a diesel engine, a generator, a battery pack and electric traction motors. The traction motors were connected to a dynamometer and the drivetrain was tested at various loads. The data is currently being analyzed for future publication.

Two small scale autonomous ground vehicle test platforms were constructed from $1/10^{th}$ scale RC model vehicles. The control system is based on the open-source APM software and runs on the open-hardware Pixhawk autopilot platform. This system will be used to test control methods and multiple-vehicle coordination algorithms for accomplishing field operations.

Testing was also performed on tablet-based location services. While general accuracy was one concern, the tablets were also used to estimate the areas of vegetable plots used in a community supported agriculture operation. The areas of the plots provided by the tablets could have significant (up to 16%) errors in their estimates. The results of this testing were presented at a conference and are being prepared for publication.

Impacts:

- Development of a series hybrid drivetrain allows combining the simplicity, controllability and efficiency of electric motors with the energy density of liquid fuels. It also permits operation of the internal combustion (IC) engine at its most energy efficient point. A further benefit is the decoupling of the power source from the ground drive. This allows for substitution of the standard IC engine with alternative-fuel engines, fuel cells, or other power sources. In comparison to field grain crops, machinery operating in specialty crops is often operated for shorter periods of time where it could even be feasible to utilize a battery pack for energy storage and the electrical grid for low-cost energy supply.
- Tablet and especially phone based computing platforms that have built-in location services are seeing widespread adoption in agriculture. Many apps are available for agricultural purposes that utilize these location services. Unfortunately, they provide very little feedback to users at to their accuracy. In order to properly use these systems, farmers need to have more understanding of the accuracies. The tablet testing has been useful to establish a baseline accuracy that can be communicated with producers interested in using the technology in their operations.

Publications:

Dvorak, J., Hasani, H. 2014. Testing of Tablet-Based GPS Systems. ASABE Paper No. 141922411. St. Joseph, Mich.: ASABE

Oklahoma

Participants: Ning Wang, Paul Weckler, Oklahoma State University.

Accomplishments

Enhancing Pecan Production and Processing Using Sensor Technology

Activities:

- Pecan yield measurement technique using backscattered terrestrial microwave sensing.
- Dielectric spectroscopy for estimating quality of in-shell pecans.
- Wireless image sensor networks for monitoring the population of pecan weevils.
- Optical sensors and algorithms that adequately predict plant N status for nitrogen management.
- X-ray machine vision inspection systems for pecan defect identification

Output:

- A prototype of an in-field, pecan weevil population monitoring sensor network system
- Image processing algorithms for the x-ray-imaging-based, pecan quality evaluation system
- Approaches for *in situ* determination of N status for pecan trees
- Journal publications on microwave backscatter response of pecan tree and VIS/NIR spectroscopy-based methods for pecan nitrogen concentration prediction
- Conference presentations on in-field pecan weevil monitoring sensor network, x-ray imaging and dielectric spectroscopy for pecan quality evaluation

Impact

Accurate estimates of pecan yields prior to harvest are critically important for both production management decisions and marketing. Microwave energy has the ability to penetrate through leaves in the canopy to interact with nuts obscured from view by optical sensing. A microwave-based, non-contact, in field evaluation system will provide a rapid tool for pre-harvest yield prediction.

Producers continually seek methods to improve orchard management, including nitrogen fertilization. Rapidly escalating nitrogen (N) costs have made this a high priority among pecan producers nationwide. Traditionally, N is applied once or twice per season. Application rates usually exceed the minimum N requirement for optimum production. The sensing approach developed in the research could help producers on reducing N inputs while maintaining production levels.

In Oklahoma, native pecan production accounts for about 90 percent of the state's crop. One of the major factors affecting pecan production is pest problems (insects and diseases). Oklahoma pecans have a good reputation for quality of nut meats, but also are known for containing larvae of the pecan weevil. Hence, the research work target at developing efficient and cost-effective tools to monitor pecan weevil population in orchards for pecan researchers and growers.

Publications

Hardin, J. A., C. L. Jones, P. R. Weckler, N. O. Maness, J. W. Dillwith, and R. D. Madden. 2013. *Rapid in situ Quantification of Leaf Cuticular Wax Using FTIR-ATR. Transactions of the ASABE*, 56(1): 331-339.

Hardin, J. A., P. R. Weckler, and C. L. Jones. 2013. *Microwave Backscatter Response of Pecan Tree Canopy Samples for Estimation of Pecan Yield in situ Using Terrestrial Radar*. *Computers and Electronics in Agriculture*. 90 (2013): 54-62.

S. K. Mathanker , P. R. Weckler, N. Wang. 2013. *Thz Applications In Food And Agriculture: A Review, Transactions of the ASABE*. 56(3): 1213-1226.

Wang, N. 2013. Challenges and opportunities of nondestructive sensing technology in food and agricultural applications. The 9th International Workshop on Nondestructive Quality Evaluation of Agricultural, Livestock, and Fishery Products. November 19-22, 2013. Taipei, Taiwan. (Invited)

Oregon

Participant: Seavert, Clark (clark.seavert@oregonstate.edu) - Oregon State University

Accomplishments:

AgBiz Logic™
AgBiz Logic™ will be a publicly available online, user-friendly, interface to increase and enhance grower participation in assessing the economics and financial impacts of adopting technology and integrating the existing capital investment and whole farm financial tools of *AgProfit™* and *AgFinance™* to measure efficiencies and profitability of technology adoption.

The efforts to develop *AgBiz Logic™* have been underway for the past nine months, as a capstone project by three students working towards a Bachelors of Science in Computer Science (OSU). The capstone course (required for receiving a computer science degree) is a one-year course sequence that exposes students to the challenges of engineering design and project management. As part of this course, students also learn vital "soft skills" (e.g. project management, documentation, etc.) as they design, build and test a product for their sponsor. For their capstone course sequence, OSU-College of Engineering students Sean Hammond, John Dong and Eric Zubriski have been developing the website and database for *AgBiz Logic™*.

AgEnvironment™
To allow agricultural producers to account for environmental impact when analyzing technology adoption, the *AgEnvironment™* module will be incorporated into *AgTools™* suite of programs and integrated into *AgBiz Logic™*. *AgEnvironment™* captures the onsite, offsite, and global environmental impacts. Producers to make key business decisions from an environmental and economic standpoint will use this information.

Onsite environmental measurements will include insecticides, fungicides, miticides, herbicides, fertilizers, other petroleum-based products, and prices received for crops. Offsite environmental impacts will be measured by soil erosion run-off and spray drift. Global environmental impacts are measured in the form of greenhouse gas (GHG) emissions and carbon sequestration.

- **Outputs**:

AgBiz Logic™: At the end of June 2014 the website and database was near completion, without the data display features or integration of *AgProfit™* and *AgFinance™*.

AgEnvironment™: The Environmental Impact Quotient (EIQ) values from Cornell University's Integrated Pest Management program was chosen to compare the environmental impact of pesticides. A sweet Cherry grower from The Dalles, Oregon, provided five years of pest management spray records to evaluate the effectiveness of the EIQ values.

To measure global environmental impacts the Cool Farm Tool (CFT) will be assessed as to its applicability to *AgEnvironment™* module. CFT is an online Green House Gas (GHG) calculator for farming, developed by Unilever and researchers at the University of Aberdeen (Cool Farm Institute, 2014). This tool provides a detailed breakdown of GHG emissions that show how aspects of the farm contribute to these emissions. The CFT requires data such as fertilizer use, soil properties, pesticide applications, land management changes, electricity use, diesel use, etc. It provides total emissions, emissions per acre, and emissions per pound of product. The cherry grower from The Dalles is providing data for this analysis as well as for the EIQ values.

- **Activities**:

AgBiz Logic™: The students estimate that another year is required to have a fully functional website, database and decision tool integration. They recommend three students - two students focusing on web design and another on database management - in next year's capstone course should take on these tasks.

AgEnvironment™: Jenna Way, an OSU undergraduate student, presented the results of the EIQ values when used with the grower spray records at the April 11, 2014 Wasco County Orchard Managers Breakfast Meeting. About 75 growers and field people attended. The response was favorable to using *AgEnvironment™* as a tool in their decision making and recommended that OSU Extension use the EIQ values in future versions of the "2014 Mid-Columbia pest control program for cherries in the 2014 Pest Management Guide".

- **Milestones**:

AgBiz Logic™: To ensure continuity between the website and database development from year to year and meeting our target of a June 2015 launching of *AgBiz Logic™*, a MS student in the College of Engineering (supervised by PI Seavert) will be hired to supervise the capstone course students and assist in the development of *AgBiz Logic™*.
AgEnvironment™: One student has been accepted into the OSU-Department of Applied Economics graduate program and she will continue assessing the already developed environmental tools and their applicability to agricultural producers and how to incorporate the data into the *AgTools™* software.

Impacts:

None to date

Publications:

None to date

Pennsylvania

Participants: Heinemann, Paul (hzh@psu.edu) Penn State (attended 2013 project meeting)
Schupp, James – Penn State
Baugher, Tara – Penn State
Liu, Jude – Penn State

Accomplishments:

Mechanized thinning: A 1/4-scale robot was fabricated and tested for selectively thinning peach blossoms. In the lab, using simulated peach blossoms at random positions, the heuristic thinning algorithm accurately controlled the robotic arm and end effector performance, reaching the goal of removing at least 95% of target blossoms.

Apple harvest assist: A low-cost harvest-assist device for apple orchard platforms was designed and fabricated. The device had four main components: receiver (where pickers placed the apples), two transport tubes, manifold, and distributor (which distributed the apples into a standard bin). After lab tests on a frame, the device was mounted to an Orsi Eco-pick mobile platform. Field-testing was performed in October 2013. Results showed that the apple receiver and the transport tube did not bruise apples, but the bruising levels were unacceptably high between the manifold and the bin. The manifold and distributor were redesigned in 2014 and were lab tested. Field tests will be performed in October 2014. Ergonomic and efficiency studies comparing the harvest assist device with standard ladder and basket picking began in 2014.

Automated pruning: Pruning of both apples and grapes, once thought to be a mysterious blend of art and science, has been described by a set of rules. These rules have been evaluated and compare favorably with human-pruned trees and vines. We are using these rules to develop automated decision systems, and to educate and train human pruners to prune their crops more effectively and efficiently. Apple pruning rules developed through this project have been published at http://extension.psu.edu/plants/tree-fruit/news/2013/renewal-pruning-for-high-density-apple-plantings.

We conducted four experiments at the Penn State field laboratory and the orchard of one commercial partner to develop and refine pruning rules. The data appear to encapsulate optimal pruning with similar effects as human pruning. These rules will also prove valuable as an educational tool to help growers make pruning cuts that result in favorable outcomes.

The principle project communication tool is the project website located at http://www.pruningautomation.com. Penn State hosted a project team and advisory panel meeting. Advice from the advisory panel (and other invited industry personnel) were recorded and used in future planning. A technology transfer workshop was conducted for 125 participants, and a technology transfer tour was conducted for 325 growers from 25 states. Orchard employees attended the pruning workshop, which was presented in both Spanish and English. Technology transfer tour participants who completed an exit survey (n=67) indicated that the three main obstacles to grower adoption of automation were cost, reliability of equipment and lack of equipment flexibility

Impacts:

(None yet from Penn State)

Publications:

Baugher, T.A., P.H. Heinemann, J.S. Schupp, and K.M. Lewis. 2013. Innovations in peach thinning. Compact Fruit. 46(3):23-25.

Caplan, S., B. Tilt, G. Hoheisel, T. Baugher. 2014. Specialty crop growers' perspectives on adopting new technologies. HortTechnology 24: 81-87.

Schupp, J., T. Auxt Baugher, P. Heinemann, E. Winzeler, T. Kon and M. Schupp. 2013. Labor efficient apple and peach production. Compact Fruit 46(2):17-19.

Zhao, Z., P.H. Heinemann, J. Liu, J.R. Schupp, and T.A. Baugher. 2014. Design, fabrication, and testing of a low-cost apple harvest-assist device. ASABE Paper No. 141839738. American Society of Agricultural and Biological Engineers. 13 pp.

Washington

Participants: Qin Zhang; Karen Lewis; Manoj Karkee. Washington State University.

Accomplishments

- Development of mechanical harvesting technologies for fresh market fruit has been one of major focuses for the WSU research team. A few generations of sweet cherry harvesting prototypes have been designed, fabricated and tested in both research and commercial orchards from 2009 to 2013. Repeated field trials verified that the tree training will play a big role in the effectiveness of mechanical harvest; harvesting efficiency varied from only 50% of hand picking on traditional tree canopy to 10 times faster from "Y-trellis" fruiting wall trees.
- Our team also worked on fresh market apple harvesting concepts. Pattern shaking, linear shaking and twisting mechanisms were evaluated to detach fruit from stem. Effectiveness of these systems depended on apple variety. Targeted shaking showed a potential for fresh market apple harvesting; future efforts should be in developing appropriate catching mechanism. Mechanical-assist technologies were also extensively studied to improve the harvesting efficiency in fresh market apple harvest. Four different platforms, including mobile carrier and pneumatic fruit conveyer, were tested in commercial orchards. Economic and safety analysis of using such platforms were also performed. The mechanical-assist technology developments also included the study of a robotic solution for bin handling in high density apple and cherry orchards to improve both the worker efficiency and safety in orchards.
- Other research activities performed by the team include precision canopy and water management based on both light penetration and orchard micro-climate measurements, automated cane-berry canopy management, effective canopy or target zone chemical delivery technologies, and in-orchard sensing technologies for various automated agricultural operations.

Impact

- Using this multi-state project as a platform, efforts have been made on establishing research and outreach programs at Washington State University. We have formed a trans-disciplinary research and extension team, consisting of engineers, computer scientists, horticulturists, economists and extension specialists, who are affiliated with the WSU Center for Precision and Automated Agricultural Systems (CPAAS). Bilateral and multilateral research and education collaborations established during the course of this project allowed us to send more than a dozen person-times of graduate students and faculty members to universities in Chile, China, Italy, Japan, Malaysia and New Zealand and to host over 10 person-times students and faculty members from Brazil, China, and Malaysia either for internship training, collaborative research, or academic exchanges.

- Developed systems/devices were demonstrated at field days, technology shows/expos, and more than a dozen collaborating trials in commercial orchards/farms, with many of those research results being presented via trade journal articles, numerous TV and local newspaper converges in 2013. In this period we also conducted numerous presentations at industrial conferences/shows to directly reach over 500 growers, researcher and other stakeholders. We also presented more than 10 papers or posters at different regional, national and international professional conferences, and made a few keynote presentations or invited seminars at international professional conferences or higher education institutes to disseminate our research outcomes. The impact of developed integrated systems technology is very significant. It could help specialty growers to achieve their production goal of increasing the yield through more efficient production management and implementation. For example, thinning blooms using mechanical tools could increase fruit size and quality in cherry and stone fruit while minimizing thinning cost. Use of mechanical cherry

harvesters could increase worker productivity and safety by replacing ladders in harvest.

- A few devices have been validated in extensive field trials in commercial orchards/farms. It includes, but not limited to, hand-held mechanical blossom thinners, orchard harvest labor management systems, high-density orchard light penetration measurement system, robotic twining machine for hop production, and site-specific precision irrigation control system for apple orchard. Among them, the technology of hand-held blossom thinning device and orchard harvest labor management system has been made available to local equipment fabricators for promoting the commercialization of research outcomes as useful tools for growers.

Publications

US Patent:
Zhang, Q., He, L., Charvet, H.J., (2013). Knot-tying Device and Method
Application Number: US 8,573,656 B1 Application Date: 11/5/2013

Book Chapter: Published
Zhang, Q., Shao, Y., Pierce, F.J. (2013). Agricultural infotronic systems. In: Zhang, Q., Pierce, F.J. (eds). Agricultural Automation Fundamentals and Practices, CRC Press, Boca Raton, FL. pp. 41-62.
Karkee, M., Steward, B. Kruckeberg, J. (2013). Agricultural infotronic systems. In: Zhang, Q., Pierce, F.J. (eds). Agricultural Automation Fundamentals and Practices, CRC Press, Boca Raton, FL. pp. 263-294.

Books: Published
Zhang, Q., Pierce, F.J. (2013). Agricultural Automation Fundamentals and Practices. CRC Press, Boca Raton, FL. (397p).

Journal Articles: Published
Du, X., Chen, D., Zhang, Q., Scharf, P.A., Whiting, M.D. (2013). Response of UFO (upright fruiting offshoots) on cherry trees to mechanical harvest by dynamic vibratory excitation. Transactions of the ASABE. 56(2): 345-354.

Wang, M., Wang, H., Zhang, Q., Lewis, K.M., Scharf, P.A. (2013). A hand-held mechanical blossom thinning device for fruit trees. Applied Engineering in Agriculture. 29(2): 155-160.

He, L., Zhang, Q., Charvet, H. (2013). A knot-tying for robotic hop twining. Biosystems Engineering.114(3): 344–350.

He, L., Zhou, J., Du, X., Chen, D., Zhang, Q., Karkee, M. (2013). Energy efficacy analysis of a mechanical shaker in sweet cherry harvest. Biosystems Engineering, 116(4): 309-315.

Zhou, J., He, L., Zhang, Q., Du, X., Chen, D., Karkee, M. (2013). Evaluation of the Influence of Shaking Frequency and Duration in Mechanical Harvesting of Sweet Cherry. Applied Engineering in Agriculture, 29(5): 607-612.

Theses/Dissertations: Published
Wang, M. (2013). A Hand-Held Mechanical Device for Target Blossom Thinning in Sweet Cherry. Ph.D. Dissertation, Washington State University.