PennState
College of Agricultural Sciences

PROPOSAL TRANSMITTAL

Date: 12/19/2018 **PSU Ref. No: 205990**

Title: Evaluation of Effective Canopy Depths of Apple Trees for Optimal Machine Sensing Performance - Year 2

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Proposed Project **5/1/2019 - 12/31/2020** **Total Project Request: $12,885**

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1. Title

Evaluation of Effective Canopy Depths of Apple Trees for Optimal Machine Sensing Performance – Year 2/2

2. Personnel

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James Schupp (co-investigator), Professor, Department of Plant Science, Fruit Research & Extension Center, Penn State

Tara Baugher (co-operator), Senior Educator, Penn State Extension, Penn State

Long He (co-operator), Assistant Professor, Department of Agricultural and Biological Engineering, Fruit Research & Extension Center, Penn State

3. Duration of Project: One year (May 1, 2019 – Dec 31, 2020)

4. Justification

Problem: As a continuation of 2018's effort, we propose to study effective canopy depths of apple trees for optimal sensing performances. As the labor shortage grows, the past decade has seen the rapid development of mechanized solutions for manual tasks for orchard crop production. Our project team has been developing various mechanized systems for orchard management such as tree pruning and thinning, and fruit harvesting (Schupp et al., 2008, 2011a, 2017; Baugher et al., 2009, 2010a, 2010b; He et al., 2017). Although previous research has established that developed platforms or machines improved productivity and economic return, many of them have a potential for improvement to better serve the intended tasks. To achieve human-like qualities in orchard management, agricultural robots must heavily rely on sensing with uncertainties related to the environment, position information and execution of the task.

What this project will address and a summary of previous works: We propose to quantify the impact of various canopy depths on machine sensing performances in a Tall Spindle orchard system. Developed sensing systems will measure the size and count of apples with at various times early in the season for forecasting potential yield in an orchard. Previous studies have shown the beneficial effects of narrower tree canopies in the mechanization of orchard management. Schupp and Baugher (2011b) reported that the adoption of narrow tree wall systems enhances the benefits of mechanical thinners and offers a near-term solution of fruit grower profitability. Miller et al. (2011) stated that narrowing canopy widths has increased the viability of mechanized bloom and green fruit thinning in peaches. This project will focus on resolving uncertainty about what levels of canopy density should be chosen to ensure optimal sensing performances. In the previous year, we developed an image acquisition prototype based on a ground vehicle (Figure 1). The developed system consisted of three cameras, a laptop, and a battery to supply powers to electronics needed in the image acquisition. We tested two commercially available cameras (1) Microsoft Kinect 2.0 (Microsoft Corporation, Redmond, WA) and (2) Intel Realsense D-435 (Intel Corporation, Santa Clara, California) that can acquire RGB, Near-infrared (NIR), and depth image streams. Also, we developed a computer vision algorithm to identify each unique fruit detection in a video sequence without double counting fruit. Furthermore, counting must also be tolerant of error from both the detector and tracker. To address these issues our object counting algorithm takes a pipelined approach (Figure 2). Figure 2 shows the general procedure, as well as detailed descriptions for detection, translations, and matching steps. The developed algorithm was published on two international conferences and presented at multiple seminars and field day (Choi et al., 2018a, 2018b; Jarvinen et al., 2018). **In Year 2, we will focus on developing and testing sensing techniques using drone applications.**

Figure 1. An image acquisition prototype using a ground vehicle as a sensing platform. The platform was equipped with multiple cameras to capture images of an entire canopy.

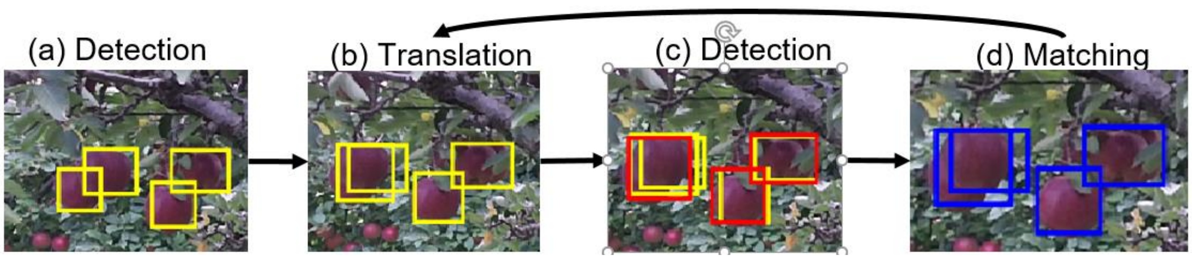

Figure 2. Visualization of detection pipeline in a video sequence. (a) Apples are detected in the first frame, (b) apple positions are estimated for the second frame, (c) a new set of detections are computed for the second frame (shown in red), and (d) the two sets of detections are matched to create a single set of apple positions (Jarvinen et al., 2018).

Benefits of this project to agricultural communities: Among the SHAP's research topic priorities, this project contributes to (1) Horticulture: Integration of New Technology for Improved Farm Efficiency and Decision Making, and (2) Ag Engineering: (i) Sensor Technologies, and (ii) Use of New Technology to Improve Data Collection for Decision Making. The proposed sensing system for apple size and count estimation can be combined in the mechanization of various tasks in orchard management such as pruning, thinning, and harvesting. In addition, the quantitative analysis of the impact of various canopy depths on machine sensing will promote the adoption of narrow fruit canopies. The narrow fruit canopies will increase the optimal distribution of sunlight into the lower and inner portions of the canopy, produce uniform crop load and fruit quality, which makes orchard production systems more accessible for automated precision agriculture technologies (Lewis, 2016). Precision agriculture technologies will improve the quality of harvested fruit and increase crop yields in apple orchards. Additional benefits of this project include increased economic returns, a decreased environmental footprint, improved workforce safety, and health, and increased labor-use efficiency.

5. Objectives

The **primary goal** is to investigate the relationship between canopy depths and machine sensing performances in a Tall Spindle apple orchard system. The objectives of the project are below.

Objective 1. Development of sensing platforms using an unmanned ground vehicle (UGV) and an unmanned aerial vehicle (UAV) for apple size and count estimation (Choi and He),
Objective 2. Field tests to compare the performance of developed sensing systems with various pruning conditions and the use of plant growth regulators (Choi, Schupp, and Baugher).

6. Procedures

Objective 1. Development of sensing platforms for apple size and count estimation - Vision sensing systems to measure counts and sizes of apples in a canopy will be developed for forecasting yield on an individual tree basis. Various fruit growth stages, beginning at fruit set, will be included in a data set to achieve a stable performance of machine sensing regardless of the stage of fruit growth. In recent works, Choi et al. (2015; 2017) addressed the early estimation of citrus yields using depth images to calculate 3D information of fruit. A similar approach will be taken by Choi's team to build an apple size and count estimation system. RGB and near-infrared (NIR) images will be combined with state-of-the-art deep learning models to detect apples in a canopy with high accuracy in various illumination conditions in orchards. Depth images will be used to accurately measure sizes of apple at different distances from the sensors. Also, two sensing platforms, (1) an unmanned ground vehicle (UGV) and (2) an unmanned aerial vehicle (UAV) will be utilized to investigate the impact of different types of platforms on the sensing performance. For a UGV platform, a stack of multiple cameras will be mounted to capture images of an entire tree canopy without missing areas (Figure 3, left). On the other hand, a single camera will be mounted on a UAV and capture images along with low altitude flight trajectory (Figure 3, right). The developed systems will be compared to find out the most efficient platform for a Tall Spindle apple orchard.

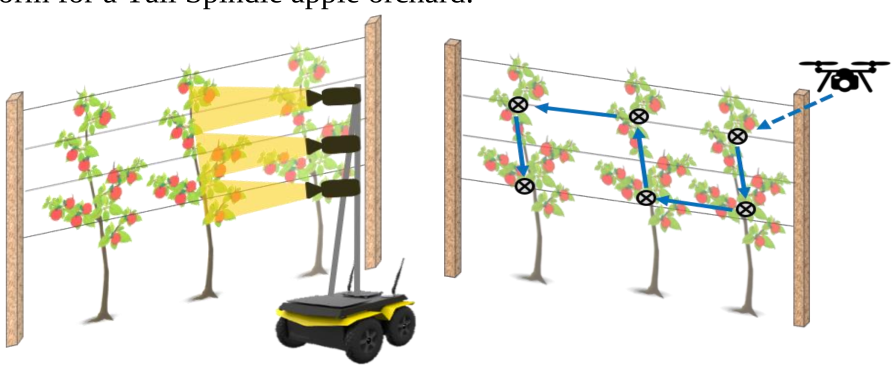

Figure 3. Initial design ideas for sensing platforms. Left: a UGV platform with multiple cameras to capture images of an entire canopy. Right: UAV flight trajectory (blue arrows: flight path, ⊗: image acquisition location) to capture images of an entire canopy with a single camera.

Objective 2. Field tests of developed sensing systems using various pruning conditions - Field tests of the sensing systems using UGV and UAV will be conducted in an established high-density apple orchard, Penn State Fruit Research and Extension Center, Biglerville. Three levels of pruning severity, based upon a pruning severity index for apple trees (limb to trunk ratio - LTR), will be adopted for the tests. According to recently published guidelines (Schupp et al., 2017), the LTR is calculated from the sum of the cross-sectional area of all branches on a tree at 2.5 cm from their union to the central leader divided by the cross-sectional area of its central leader at 30 cm from the graft union. The LTR metric provides a measurable way to define and create different levels of pruning severity and achieve consistent outcomes and allows a greater degree of accuracy and precision for dormant pruning of tall spindle apple trees. For each level of pruning severity, 3-tree plots will be set up with the center tree as the data tree, but with the adjacent tree to each side receiving the same canopy treatment. Also, an additional tree plot of trees treated with the plant growth regulator (PGR), Apogee, will be set up in the field tests. The use of Apogee increases the distribution of sunlight into the lower and inner portions of the canopy, but it has been unknown how this would affect machine sensing capabilities. Results of the field tests will be analyzed in terms of apple detection accuracy (false positive/negative rates) and size estimation accuracy (root-means-square-error, RMSE, between actual sizes and estimated sizes of apples) for four types of canopy manipulation (three levels of pruning severity and Apogee treatment). Also, estimated yield by the sensing systems will be compared with actual harvest data (fruit number per tree, fruit size distribution, yield, and crop density). Additional field experiments in Russell E. Larson Agricultural Research Center (Rock Springs) will be conducted to evaluate the sensing performance to a vertical wall hedgerow system for two apple cultivars proposed in the SHAP research project 'Effects of Maintenance of Training Systems to a Hedgerow' by Dr. Robert Crassweller. Using the suggested quantitative analysis, final outcome of this project will be the identification of efficient and human/machine friendly canopy depths in a Tall Spindle apple orchard system.

7. Budget

Year 2 - $12,885

Hourly wages –

- Wages ($7200 = $15/hr*4hr/day*5day/wk*24 wk) for a student are requested. The wage payroll student (TBD) will work with Dr. Choi on field experiment as well as data analysis of sensing systems.
- Wages ($4,000) for a technical assistant is requested. The technician (TBD) will work with Dr. Schupp to manage different levels of dormant pruning or summer pruning and

Fringe Benefits – Fringe benefits ($875) are computed using the fixed rates of 7.81%.

Travel - $800

- Travel expenses ($410) are requested for Dr. Baugher (collaborator of the project). The expenses will cover the costs associated with four field experiments in commercial apple orchards in PA.
- Travel expenses ($400) are requested for Dr. He (collaborator of the project). Dr. He will participate in field tests as well as regular monthly project meetings in University Park.

References

Baugher, T. Auxt, Lewis, K., Schupp, J., Harsh, M., Seavert, C., Auvil, T. 2009. Mobile platforms increase orchard management efficiency and profitability. Proc. International Society for Horticultural Science – Application of Precision Agriculture for Fruits and Vegetables, *ACTA Horticulturae* 824:361-364.

Baugher, T., Schupp, J., Lewis, K., Hoheisel, G., Ellis, K., Ames, D. & Remcheck, J. 2010a. Pilot orchards provide laboratories in the field to increase industry adoption of labor assist and precision technologies. American Society of Agricultural and Biological Engineering Annual Convention. Abstract.

Baugher, T. A., Schupp, J., Ellis, K., Remcheck, J., Winzeler, E., Duncan, R., Johnson, S., Lewis, K., Reighard, G. & Henderson, G. 2010b. String blossom thinner designed for variable tree forms increases crop load management efficiency in trials in four United States peach-growing regions. *HortTechnology,* 20(2)**,** pp 409-414.

Choi, D., Lee, W. S., Ehsani, R., Schueller, J. K. & Roka, F. Machine vision system for early yield estimation of citrus in a site-specific manner. 2015. ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers.

Choi, D., Lee, W. S., Schueller, J. K., Ehsani, R., Roka, F. & Diamond, J. 2017. A performance comparison of RGB, NIR, and depth images in immature citrus detection using deep learning algorithms for yield prediction. ASABE Annual International Meeting. American Society of Agricultural and Biological Engineers.

Choi, D. & Jarvinen, T. 2018a. Fruit detection and tracking for yield prediction in apple orchards," 100th Anniversary Field Day, Penn State Fruit Research and Extension Center, Biglerville, PA.

Choi, D. & Jarvinen, T. 2018b. A video processing strategy using camera movement estimation for apple yield forecasting. Proceedings of the 9th International Symposium on Machinery and Mechatronics for Agriculture and Biosystems Engineering, May 28-30, 2018, Jeju, South Korea.

He, L., Fu, H., Sun, D., Karkee, M. & Zhang, Q. 2017. Shake-and-Catch Harvesting for Fresh Market Apples in Trellis-Trained Trees. *Transactions of the ASABE,* 60(2)**,** pp 353-360

Jarvinen, T., Choi, D., Heinemann, P., & Baugher, T. A. 2018. Multiple object tracking-by-detection for apple fruit counting on a tree canopy. 2018 ASABE Annual International Meeting, Paper No. 1801193, July 29 – Aug 1, 2018.

Lewis, K. 2016. Mechanization of orchard practices. Washington State University Extension. Available: http://extension.wsu.edu/impact-reports/mechanization-of-orchard-practices/.

Miller, S., J. Schupp, T. Baugher, and S. Wolford. 2011. Performance of mechanical thinners for bloom or green fruit thinning in peaches. Hort-Science 46:43–51.

Schupp, J., Baugher, T. A., Miller, S., Harsh, R. & Lesser, K. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. *HortTechnology,* 18(4)**,** pp 660-670.

Schupp, J., Baugher, T., Winzeler, E., Schupp, M. & Messner, W. 2011a. Preliminary results with a vacuum assisted harvest system for apples. *Fruit Notes,* 76(4)**,** pp 1-5.

Schupp, J., and T. Baugher. 2011b. Peach blossom string thinner performance improved with selective pruning. HortScience. 46:1486-1492.

Schupp, J. R., Winzeler, H. E., Kon, T. M., Marini, R. P., Baugher, T. A., Kime, L. F. & Schupp, M. A. 2017. A Method for Quantifying Whole-tree Pruning Severity in Mature Tall Spindle Apple Plantings. *HortScience,* 52(9)**,** pp 1233-1240.