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College of Agricultural Sciences

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

Submitted to: State Horticultural Association of Pennsylvania
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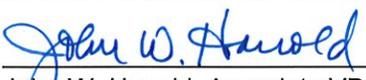
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1. Title

Evaluation of Effective Canopy Depths of Apple Trees for Optimal Machine Sensing Performance

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

2 years (May 1, 2018 – April 30, 2020)

4. Justification

Problem: 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; Baugher et al., 2009; Baugher et al., 2010a and 2010b; Schupp et al., 2011a; He et al., 2017; Schupp 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 many uncertainties related to the environment, position information and execution of the task itself. One of the main obstacles in specialty crop mechanization is the variability of tree canopies which is dynamic and complex due to the differences between individual plants. Such 4-D architecture implies the absence of a consistent pattern for sensors to find limbs of trees or fruits on a limb (Fisher, 1992). Recently, tree structures with more uniform canopy shapes have been introduced such as Tall Spindle and V-Shape planting systems. These systems have shorter and narrower canopies which are favorable conditions for the robot and machine sensing. Also, trees treated with plant growth regulators (PGRs) suppress the extension of the shoots and produce a more compact canopy, resulting in a tree canopy friendlier for machine sensing. However, there have not been enough studies to analyze the impact of canopy depths on the performance of sensing systems. Also, commercial apple growers will need guidance to make a right decision in choosing tree structure and pruning severity to prepare for a future transition to a fully automated production system.

What this project will address and a summary of previous works: In this project, 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. For example, 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. The results of previous studies imply that in general, a shorter and narrower tree canopy provides higher accuracy of agricultural machines. However, there is still insufficient data for the quantitative analysis to represent the relationship between canopy depths and the performance of machine sensing systems. This project will focus on resolving uncertainty about what levels of canopy density should be chosen to ensure optimal sensing performances while preserving crop yields.

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, (2) Ag Engineering — Sensor Technologies, and (3) Ag Engineering — 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 and training trees, green fruit thinning, harvesting, etc. 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 precision agriculture practices and automated technologies (Lewis, 2016). Site-specific crop management using 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** of this project is to investigate the relationship between canopy depths and machine sensing performances in a Tall Spindle apple orchard system. The specific objectives of the project are below (both objectives will be carried out simultaneously in Year 1 and Year 2).

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 1, left). On the other hand, a single camera will be mounted on a UAV and capture images along with low altitude flight trajectory (Figure 1, right). The developed systems will be compared to find out the most efficient platform for a Tall Spindle apple orchard.

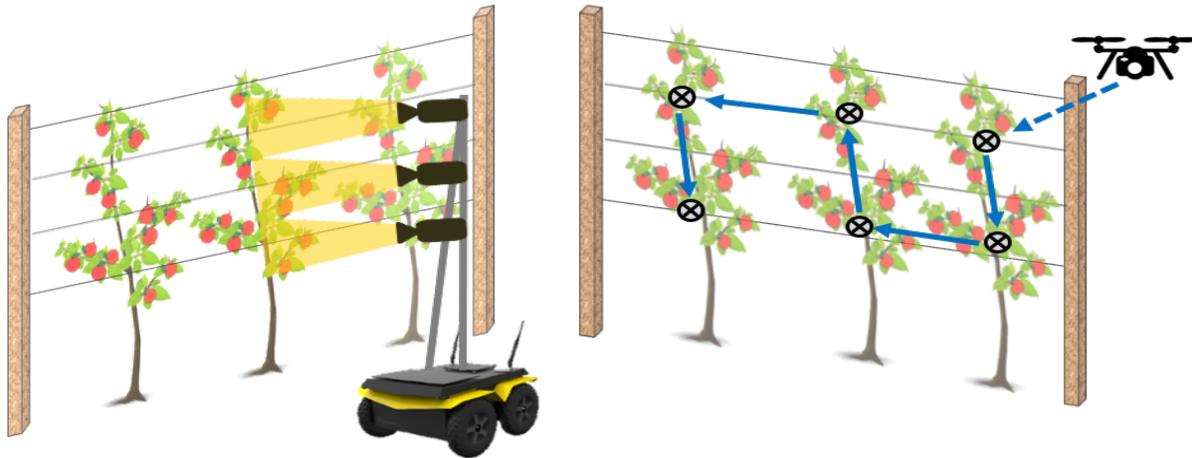


Figure 1. Initial design ideas for sensing platforms. Left: a UGV platform with multiple cameras to capture images of an entire canopy. Right: UAV flight trajectory (blue arrows: flight path, ⊗: image acquisition location) to capture images of an entire canopy with a single camera.

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 2018 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 1 - \$14,184

Hourly wages - \$11,200

- 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 collect horticultural data (yield, fruit number per limb/tree).

Fringe Benefits - \$885

Fringe benefits are computed using the fixed rates of 7.90%.

Supplies - \$1,499

Funding for purchasing an UAV (\$1,499, DJI Phantom 4 pro) is requested. The UAV will be used in developing a proposed sensing platform in this project.

Travel - \$600

- Travel expenses (\$300) are requested for Dr. Baugher (collaborator of the project). The expenses will cover the costs associated with three field experiments in commercial apple orchards in PA.
- Travel expenses (\$300) 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.

Year 2 - \$12,885

Hourly wages - \$11,200, same as Year 1

Fringe Benefits - \$885, same as Year 1

Travel - \$800

- Travel expenses (\$400) 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.

8. Other Support - none

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