# IFAS Citrus Initiative MH Annual Progress Report 2010-11

## Mechanical Harvesting and Abscission: Machine Enhancement

**Investigator:**
PI – Reza Ehsani
Co-PIs – Amanda Valentine, Joe Maja, Won Suk Lee, Kelly Morgan, Fritz Roka.

**Objective(s) Pursued:**

**Objective 1** – Develop engineering solutions to reduce trash in mechanically harvest fruit

*Task 1: To make improvements to the pull behind trash removal platform developed during 2009-2010. (Ehsani)*

- Install a new cleaning unit and other improvements
- Add ability to eliminate small fruits from harvested loads
- Implement the ability to control the speeds for conveyor belts to ensure smooth mass flow of the fruit through the machine.
- Establish the efficiency of an extended de-stemmer and install the same on existing harvesters

*Task 2: To develop a machine vision system for quantifying the fruit quality. (Lee, Ehsani)*

- Develop and mount a system of sensors to determine the fruit quality and detect those which do not meet the required standards.

*Task 3: To conduct field work to evaluate machine performance with respect to both fruit recovery and harvest debris. (Ehsani, Roka)*

- Conduct extensive field tests to collect data about trash and compare hand and machine harvesting.

*Task 4: Conducting field test to determine the effectiveness of the extended de-stemmer. (Ehsani)*

**Objective 2** – Evaluating over-the-row harvesting machines for high density groves

*Task 1: To study potential use of over-the-row harvesters for high density citrus groves.* (Ehsani, Morgan)

- Use an over-the-row blueberry harvester and make plans for necessary modifications
- Modify the harvesters for swell and pit conditions and larger tree size.
- Conduct field tests.
- Determine the list of improvements needed to effectively use the modified harvesters for high density grove conditions.
- Prepare the final report and communicate the results with the manufacturing industry and citrus growers.

**Objective 3** – Machine improvement and alternative design

*Task 1: To determine the best technology for adding a catch frame to the pull-behind harvester. (Ehsani)*

- Design and develop a catch frame to aid in the collection of fruits harvested by pull-behind mechanical harvesters.

*Task 2: To study alternative harvesting technologies that can be used by small growers. (Ehsani)*

- To develop alternative design for harvesting technologies that can be used by small growers.

*Task 3: To improve the design and study modern materials for shaker tines. (Ehsani)*

- Improve tine design to withstand the harsh loading conditions.
- Study and implementation of better materials that can reduce weight and increase strength.

**<u>Objective 4</u>** - Enhancement of the automated tine control system for mechanical harvesters. (Ehsani).
Due to the need of citrus industry and higher priority, the above objective was pursued in place of developing a computer vision system to accurately quantify the percent harvested fruit which was originally proposed.

**Progress on Objectives:**
<u>Detailed Accomplishments in 2010-2011</u>:

**Objective 1: *Task 1***
Improvements were made to the debris removal machine (de-trasher) that was developed during 2009-10 (Fig. 1a). The system was re-developed and modified (Fig. 1b) to incorporate: (i) A new cleaning system, which integrates a floating-gap technique at the initial fruit entrance on the pinch-rollers unit. This allowed larger stems and twigs to be caught and removed from the harvested load. (ii) A chain conveyor was incorporated with the pinch-roller system to create a regulated fruit-flow, thus a more regulated fruit cleaning rate. (iii) The first contact conveyor following the hopper was modified to allow undersized fruits to pass through its unit's connecting bars, thus eliminating undersized fruit from the harvested loads. (iv) A modified hydraulic valve and speed control system was incorporated to improve conveyor flow rates. Hydraulic motors were also re-configured to maximize their performance efficiency.

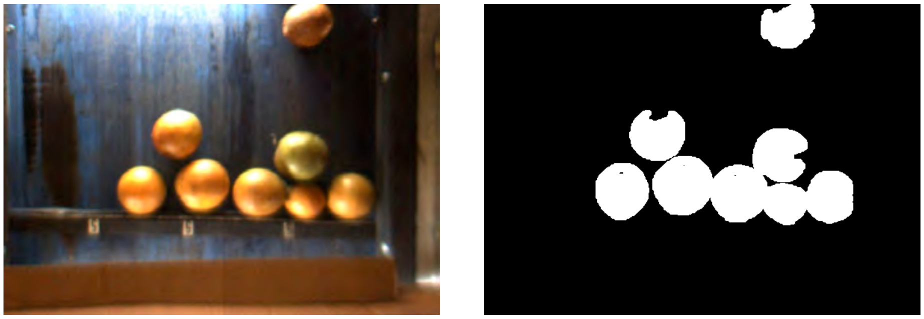
(a) (b)

Fig. 1. Debris removal machine (a) 2009-2010 and (b) 2010-2011.

***Task 2***
The machine vision hardware system (Fig. 2) for the yield estimation consisted of a CCD color camera, two white Exolights, an incremental encoder, and a data acquisition card. The image acquisition system was setup in an enclosed compartment with LED diffused light source and a camera with high frame rate (206 frames/s).

(a) (b) (c)

Fig. 2. Imaging system hardware setup: (a) CCD camera installed on the machine, (b) housing cover, and (c) encoder.



(a) (b)

Fig. 3. Image resulting from algorithm: (a) original image and (b) processed binary image.

The algorithm developed to estimate citrus yield based on machine vision included steps for image rectification, histogram based image segmentation, and mass calibration. Histogram analysis of image features showed that good separation existed between fruits and background objects in chrominance in blue (Cb) and chrominance in red (Cr). Binary images were generated using thresholds of these two features (Fig. 3).

Forty oranges of varying sizes were used to generate a calibration curve for estimating fruit mass. A regression curve was developed with a $R^2$ of 0.983. The equation used for estimating fruit mass (lb) was:

$$\text{Estimated mass (lb)} = (1.403 \times 10^{-4} \times \text{pixel area}) - 0.1967 \qquad (1)$$

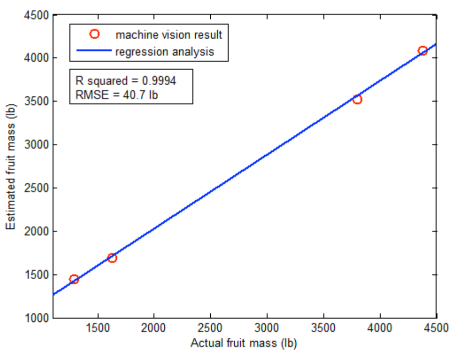



Fig. 4. Regression analysis on the validation sets.

On May 19, 2011, oranges were harvested using a continuous canopy shake and catch harvester in Lykes grove in Fort Basinger, FL. A total of five loads of harvested oranges were transferred to the de-trasher machine to clean debris. Images of oranges at the end of de-trashing operation were taken and stored for later analysis. Among these five loads, the first load was used as a training set for developing image processing algorithm, and the remaining four loads were used for validating the yield estimation algorithm. The fruit mass was estimated using equ. (1) with the total pixel area from the images as an input. The estimated mass was well correlated to the actual mass (Fig. 4) with a $R^2$ of 0.9994 and a root mean square error (RMSE) of 40.7 lb. The error ranged from 3.7-11.8%. In addition to the mass estimation, the diameter of fruits was estimated by converting diameter in pixel to diameter in inch. The minimum and maximum diameter estimated was 2.39 and 4.23 inches, respectively.

**_Task 3_**
Field data collection was performed three times to compare the trash removal percentage resulting from hand harvest, and mechanical harvesting with and without abscission. Field data was collected during the period of 4th-31st May, 2011 to assess the performance of the system. In addition to measuring the mass of trash in comparison to load cell weight of the harvested fruits, different components of trash were also segregated. The trash was divided into four parts: leaves, branches, damaged/rotten fruits and small green fruits. The trash removal rate is summarized in Fig. 5; while the components of trash are presented in Fig. 5b. It should be noted that Fig. 6 is percent of overall trash of individual harvesting method.

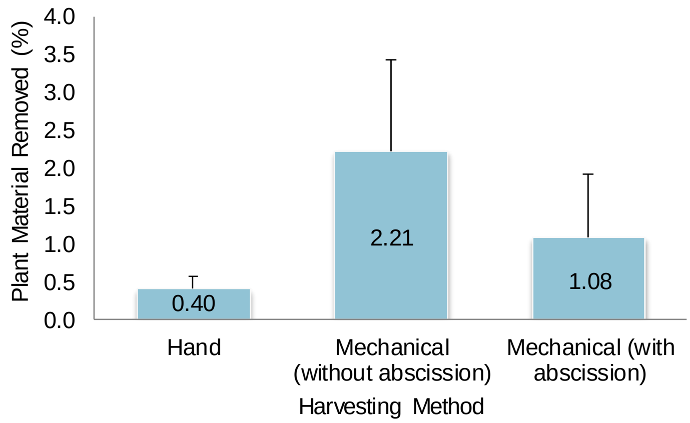



Fig. 5. Average plant material removed from harvest citrus load.

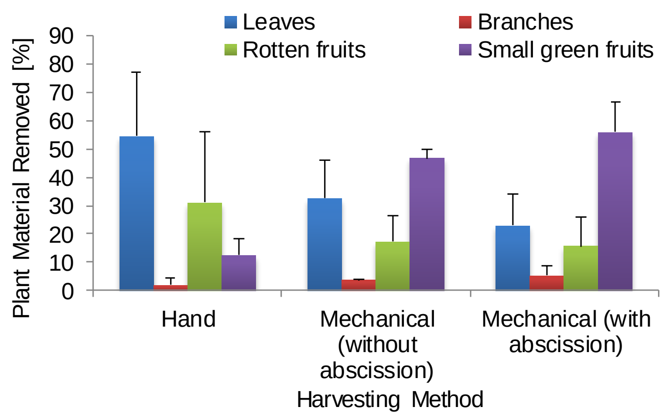



Fig. 6. Average plant material category removed from harvest citrus load.

**Objective 2: _Task 1_**
An over-the-row blueberry harvester from BEI International LLC was studied for its potential use in high density citrus groves. The machine was tested at the SWFREC experimental high density 4-year old Flying-Dragon variety citrus grove in Immokalee. The machine's physical characteristics and performance attributes were observed during harvesting, in order to determine its effectiveness with harvesting the high-density dwarf species.

The machine's physical size was appropriate for the row-spacing. It's turning radius capability was made for simple maneuverability. Due to the fact the machine was established for picking blueberries, it should be noted that modifications are necessary to improve its performance in dwarf citrus harvesting: 1. The catch conveyor contained buckets, which made it difficult to carry the orange load, due to increased size and weight. It is recommended to have a lipped-belt, along with incorporating a pinch-roller section to aid in debris removal. 2. The nylon sway picking mechanism was aggressive on the tree's limbs. The slapping motion causes some branch damage. Leaf density was affected as well. It is recommended to use a combination of forced air and mechanical force to remove the fruit from the trees. 3. The machine's base lift-height appeared limited within the swell/pit area inclination and associated depth. Modifying the wheel-base to adjust further out and up in those areas will be helpful. 4. During the tests, the machines tunnel height was appropriate. However, tree growth will occur, adjustable working height would be necessary. 5. During the tests, there were no uniform tree sizes, due to varying test treatments. The ground and picking speeds were heavily dependent upon operator judgment. A means to automate the travel and picking rate, according to varying tree characteristics, would help minimize tree damage.

Fig. 7. BEI international blueberry harvester.

**Objective 3:** ***Task 1***

The Oxbo 3210 tow-behind harvester is a candidate for a catch frame attachment, which helps prevents the fruit from hitting the ground surface, thereby making the harvesting efforts more efficient.

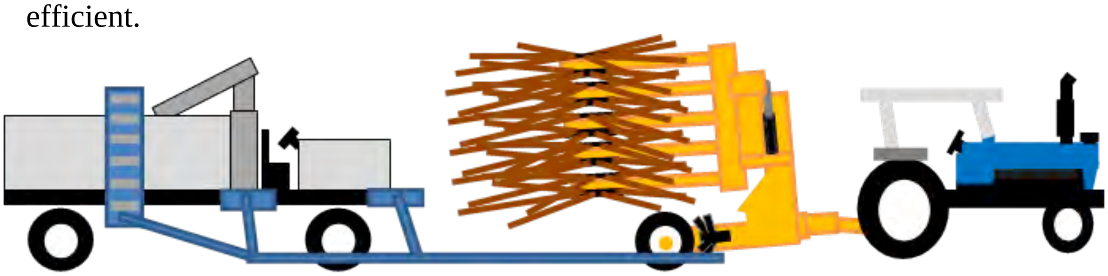


Fig. 8. Oxbo International Corp.: Tow-behind harvester 3210 followed by a Goat truck citrus catch frame and conveyor position concept drawing.

The concept of a combination pinch roller, catch plate and conveyor system attached to a Goat truck, which follows the harvester, was conceived as potential convenient solution.

Fig. 9. Catch plates contour to the trees. The fruit is conveyed to the pinch-rollers, and then conveyed into the elevator positioned on the goat truck by smaller width conveyors.

***Task 2***

To assist the small grower, a conventional goat-truck which incorporates a more suitable attachment was developed. The attachment is a single rotating tube, which incorporates segmented flappers. The device can be strategically placed within the canopy to create a branch/limb shaking force.

(a) (b) (c)

Fig. 9. (a) and (b): alternative harvesting attachment mounted on the Goat truck basket pick-up unit; (c) attachment at work inside tree’s canopy.

***Task 3***

Presently, mechanical citrus harvesters are utilizing hardened steel round tubes as a primary means to remove fruit from the trees (Tines). Preliminary studies suggest these tubes are vulnerable to breakage when subjected to high impact force with the tree’s branches/limbs. The tubes tensile strength and elastic limit are also compromised. Moreover, tubes with areas of erratic surface hardening are more likely to break in those areas, because it makes them brittle (weaker). The cantilever clamping devices are another contributor to tine breakage or lose. If the clamps are too worn, and the tines are allowed to move, they will eventually fall-out.

(a) (b) (c)

Fig. 10. (a): Oxbo self-propelled harvester 3220 cantilever-tine system working within the citrus grove. (b): Tine missing from the clamp holding unit. (c) Damage clamp holding unit.

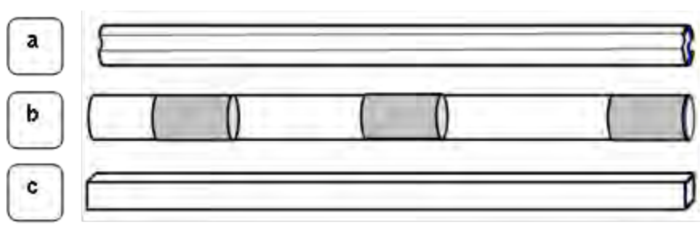



Fig. 11. Potential Tine materials and characteristics: (a) Outer segmented contour style of tubing offers increased mechanical strength. (b) Rubber inserted into the round tubes act as an impact absorbent. (c) The same outer dimension of square tubing has a higher tensile strength, compared to the round tubing

It should be noted that different tubular shapes can add strength. The same outer dimension of square tubing has a higher tensile strength, compared to the round tubing. Outer segmented contour style of tubing is more difficult to manufacturer, but has advantageous mechanical strength characteristics over the round. Rubber inserted into the round tubes act as an impact absorbent as well.

**Objective 4:**
An automated system that controls the movement of the tine based on the distance of the tree edge could potentially maximize the productivity of the pull-behind canopy shaker and improve fruit removal. Currently, this system designed by OXBO® comes with a tree follower functions and uses the pressure exerted by the tines to the tree but was not working correctly and therefore growers never used that system.

**<u>Detailed Accomplishments in 20010-11</u>:**

- Two ultrasonic sensors (SICK®) were used to measure the distance of the tine to the tree and a position sensor (ASM®) was used for measuring the movement of the tine. The position sensor serves as the feedback while the two ultrasonic sensors were the input module. The two ultrasonic sensors were placed on a vertical beam at the back of the tractor while the position sensor was placed on top of the cylinder that moves back and forth based on the movement of the tine. All the sensors were connected to our modular control box placed inside the tractor cabin. The control box used all the sensors information on moving the tine in and out of the tree.

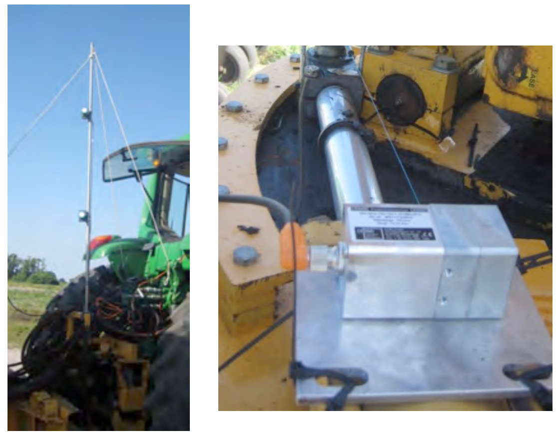


Fig. 12. (a) SICK Sensor; (b) ASM Sensor

- The main function of the two ultrasonic sensors was to minimize the problem of false distance measurement. The shortest distance reported between the two sensors will be used as the correct distance of the tree from the tine.

- The program on the control box provides different sets of configuration which enables the driver to adjust the tine based on the size of the tree on the block and can also be access wirelessly. Once calibrated the control box will used the configuration whenever it is powered. The most important configuration that the driver needs to set are the following:

  - The swing of the tine based on the tree sizes.
  - The maximum and minimum allowable distance of the sensor.
  - The maximum and minimum allowable swing of the tine.

The control box also has three output connectors which will be attached to the tine control connection block on the tractor. This will provide signal to the tractor system to move the tine in and out of the tree.


Fig. 13. Newly developed control box

The driver still have the option to do manual control even if the automatic control system is in place by using the normal manual control switches from OXBO®.

Based on the results on this work, an automatic tine control system was tested. Two distance sensors and a position sensor were used as input and feedback sensor. An experiment was made that compares the manual control of the tine where the driver does the control of the movement of the tine and the automatic tine control where the driver simply drives the tractor. Preliminary results showed that there was no significant difference between the automatic and the manual control.

**<u>Areas where progress exceeded expectations</u>:**

**<u>Objective 1:</u>** The re-developed trash removal system created a more streamline production-flow effect: 1. Incorporating a dump-lift within an increased hopper capacity volume allowed a better flow-rate into the debris removal area of the system. 2. The first conveyor not only eliminated undersized fruit, but it took larger branches and dead wood and broke them into smaller pieces, which the pinch-rollers eliminated from the system rather easily. 3. A horizontal tine device was incorporated prior to the pinch-roller area to aid in removing larger branches from the harvested load. 4. A telescoping output conveyor was incorporated to aid with easier machine-to-site transport, and conveying the load to differing trailer heights, along with making it better to adapt to different ground elevations. 5. Fruit catch guards were placed on the output conveyor to make it easier to increase conveyor speeds without worrying about excessive fruit loss, due to mid-air collisions. 6. The developed image processing algorithm yielded very good citrus yield estimation with a $R^2$ of 0.9994 and a root mean square error (RMSE) of 40.7 lb.

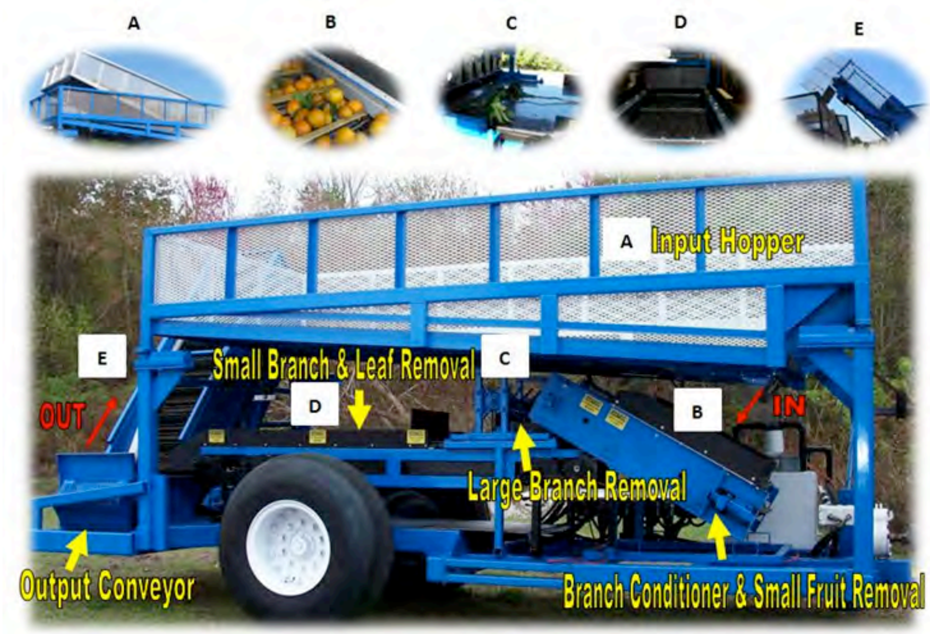



Fig. 14. Different components of trash removal system

**<u>Objective 2:</u>** Besides testing the BEI machine, an over-the-row olive harvester was provided by Oxbo International Corp., and was also tested at the SWFREC experimental high density Flying-Dragon variety citrus grove in Immokalee.

Fig. 15. Olive harvester

Observing this machine provided additional information related to machine enhancement and potential improvement areas: 1. The machine had difficulties maintaining a constant height and center position with the tree's trunk buttress area, due to slipping into the swell/pit area. The operator found it challenging to navigate. Modifying the wheel-base to adjust further out and up in those areas will be helpful. 2. The machine utilized a bow-rod picking mechanism, which caused some tree damage by catching and dragging branches. It's recommended to try a combination of forced air and mechanical force to remove the fruit from the trees. 3. The unloading conveyor was positioned over the adjoining tree row. The catch trailer must be used in the adjoining row. Following in the same row has visual advantages for the truck driver, so reconstructing the output conveyor direction might be necessary.

**Objective 3:** An over-the-row harvester worth about $500,000 was donated by Tranex, Inc. of Arcadia Florida for research purposes to Dr. Ehsani's program at the CREC. This machine will enhance research and development efforts, by providing an unlimited opportunity to study and apply differing techniques to improve performance efficiency, especially related to fruit picking mechanisms, debris removal and dealing with system navigation challenges.

Fig. 16. Over-the-row harvester

**Areas where progress didn't meet expectations:**

**Objective 1:** (i) The system's throughput capacity, thus effective flow-rate is constrained by the conveyors physical width dimensions; therefore the system's efficiency could not be enhanced to accommodate higher productivity goals, which match the mechanical harvester's production rate. (ii) During image processing, it was observed that maintaining the uniform light condition during the experiment could result in the better estimation. Objects that have similar color attributes as fruits may pose a problem in the image segmentation step. It is advised that those objects should be repainted with different color if possible.(iii) We were not able to get data for comparison of the extended de-stemmer because the redevelopment of trash removal machine took longer than expected and harvesting season ended earlier this year compared to previous years. However the extended de-stemmer unit worked for the whole season on the mechanical harvesting machine and the operator reported that he felt the extended de-stemmer was clearly reduced the trash in the load and the growers were happy with the performance of the extended de-stemmer unit.

**Objective 2:** Due to unexpected machine modification delays and transportation carrier breakdowns, the BEI harvester wasn't able to arrive on time in Florida to be further tested at the SWFREC experimental grove in Immokalee. So, machine improvements were not observed during the later harvest season.

**Objective 3:** Potential fruit picking materials were only tested via a small scale means and not field tested. The present mechanical harvester gift will allow plenty of opportunity to test materials on a full scale basis.

**Objective 4:** We meet all the objectives set for this year.

**Impact of accomplishments towards overall goals of funding:**

**Objective1:** The fruit debris removal machine provides critical information on the overall performance of mechanical harvesting machine in quantifying the total amount and type of debris created by mechanical harvesting machine. This machine now can be used as a tool in the future studies in which one can study to effects of forward speed and shaking frequency with and without abscission on the amount and type of debris.

**Objective 2:** It showed that existing commercially available mechanical harvesting machine can be used for harvesting small dwarf citrus trees with small modifications. Being able to use existing machine for other crops can reduce the design and development costs for developing new harvesting machines for high-density dwarf tress.

**Objective 3:** It is now possible to expand on the concept of developing low-cost harvesting machine for small citrus growers by developing attachment that can fit on their existing harvesting machines.

**Objective 4:** The new tine control system can improve the productivity of the operator by automating one of his job functions. This may results to increase the amount of time operator can work without getting exhausted, thereby improving overall efficiency.

**Presentations associated with 2010-2011 efforts:**

1. Ehsani, R. "Advance Mechanization Technologies for the Citrus Orchards of Tomorrow", Agricultural Equipment Technology Conference (AETC), Orlando, FL. January 11, 2010.
2. Ehsani, R. "Machine Enhancement for Mechanical Harvesting of Citrus", Immokalee, FL. May 26, 2010.
3. Ehsani, R. " Effect of Citrus Tree Canopy on the Signal Strength of a Zigbee-based Multi-node Wireless Sensor Network", The International Symposium on Wireless Sensor Network in Agriculture (ISWSNA 2010), Beijing, China, November 18-19, 2010.
4. Ehsani, R. "Development of Ground-Based Sensors for Citrus Production System", Department seminar, Biological and Agricultural Engineering Department, UC Davis, CA. Feb 24, 2010.
5. Patil, R., W. S. Lee, R. Ehsani, and F. Roka. 2010. Elimination of debris using de-stemmers on a continuous citrus canopy shake and catch harvester. ASABE Paper No. 1008384. St. Joseph, Mich.: ASABE.

6. Bansal, R., W. S. Lee, R. Shankar, and R. Ehsani. 2010. Automated trash estimation in a citrus canopy shake and catch harvester using machine vision. ASABE Paper No. FL10-123. St. Joseph, Mich.: ASABE.

**Publications from 2010-2011 efforts:**

1. Savary, S. K. J. U., R. Ehsani, M. Salyani, M.A. Hebel, and G. C. Bora. 2011. Study of force distribution in citrus tree canopy during harvesting using a canopy shaker. Journal of Computers and Electronics in Agriculture. 76. 51- 58.
2. Savary, S. K. J. U., R. Ehsani, J. K. Schueller, and B. P. Rajaraman Mishra. 2010. Simulation study of citrus tree canopy motion during harvesting using a canopy shaker. Transactions of the ASABE. Vol. 53(5): 1373-1381.
3. Bansal, R., W.S. Lee, R. Shankar, and R. Ehsani. 2011. Automated debris mass estimation for citrus mechanical harvesting systems using machine vision. Applied Engineering in Agriculture. Accepted for publication. 36 Pages. Applied Engineering in Agriculture (accepted)
4. Jadhav, J.S., J.M. Maja, and R. Ehsani. 2010. Yield monitoring system for citrus mechanical harvester. Papers of the American Society of Agricultural and Biological Engineers (ASABE). Paper No. 1009311. St. Joseph, MI: ASABE.10 pages.
5. Ehsani, R., S. Sankaran, C. Dima. 2010. Grower expectations of new technologies for applications in precision horticulture. EDIS Publication No. AE467. http://edis.ifas.ufl.edu/ae467
6. Ehsani, R. 2010. Increasing field efficiency of farm machinery using GPS. EDIS Publication No. AE466. http://edis.ifas.ufl.edu/ae466
7. Ehsani, R. and S. Udumala. 2010. Mechanical harvesting of citrus. Resource. May/June: pp. 5-6.

**Next steps:**

**Objective 1:** The existing pull-behind trash removal unit needs to incorporate instrumentation in order to constantly monitor conveyor/motor speeds, thus throughput rates. The unit needs to run throughout the entire harvesting seasons (early to late), in order to collect more significant data related to the separation of plant materials: deadwood, bad fruit (prior damage, system damaged, too soft and undersized), leaves, and branches. The image processing algorithm will be enhanced so that fruit quality such as size, color, and disease status (especially HLB) will be inspected and recorded.

**Objective 2:** The modified BEI harvester needs to be observed and evaluated during the next appropriate harvesting season, in order to determine its effectiveness with the high-density dwarf citrus, as a next step toward machine improvement efforts. Also, keep collaborating with Oxbo, in order to maintain systematic research goals, which will help growers more easily adapt to the proposed high-density dwarf citrus as an industry, due to providing a ready-to-use harvester specifically manufactured for that industry.

**Objective 3:** (1) Incorporate the fruit removal system onto the goat-truck, and then field test and demonstrate the approach to small growers. (2) On the research-based mechanical harvester, study the effect of flexible composite materials have, for removing fruit from the trees, as well as incorporate an induction knife style turbo blower system, to aid with more effective fruit removal and prevent less damage to the trees.

**Objective 4:**

(1) Further field testing of automated tine control is needed for this system to be deployed as an added functionality for the current Oxbo pull-behind canopy shaker.
(2) An updated control box which gives the driver the option to change the calibration using knobs to minimize the use of laptop.
(3) Adding an ability to control the optimal tine angle with respect to canopy

# IFAS Citrus Initiative MH Annual Progress Report 2010-11

### EFFECT OF INITIAL TREE HEALTH and IRRIGATION TIMING ON SHORT AND LONG TERM IMPACTS of MECHANICAL HARVESTING

**Investigator:**

PI – Kelly T. Morgan
Co-PIs – Robert C. Ebel

**Objective Pursued (Priority Topics):**

Priority topic studied in this project is effect of mechanical harvesting on tree health.
The objectives of this project are to determine the effect of tree condition prior to harvest and harvest method on measures of short-term and long-term tree health. The goal of the research will be the documentation of short-term and long-term impacts of mechanical harvesting on trees of selected levels of initial tree heath compared with hand harvested trees over a three year period.

Detailed Accomplishments in 2010-11:

Trees in the Ranch One grove managed by CPI were selected by tree condition on soils with similar characteristics (Malabar fine sand) and in similar landscape positions. Three tree condition categories (i.e. poor, moderate and excellent) were determined based on general tree appearance, leaf color and size, canopy density and fruit load. Leaf area index (LAI) was used to quantify initial tree condition prior to harvest and to determine effect of harvest method on tree canopy. LAI was significantly different by tree condition prior to harvest. When measured after harvest, LAI was not significantly different by harvest method. Irrigation was either applied the day before harvest or withheld for a period of 5 to 7 days prior to harvest. Pull force (i.e. energy required to detach fruit from the tree) and stem water potential (i.e. water tension of leaf equilibrated to tension in the stem) were determined the day of harvest. Significant differences in pull force was found among the irrigation treatments with a 14% reduction in pull force required to remove fruit of the water stressed trees. Stem water potential of water stressed trees were higher prior to harvest but not significantly greater compared with non-stressed trees. Sap flow flux (i.e. flow of water per unit branches cross-sectional area in response to evapotranspiration) in upper canopy branches was used as a measure of tree health. Differences among tree condition categories were found with poorer trees generally using less water than the excellent trees, but no significant differences in sap flow was found among irrigation treatments within tree condition. After harvesting, half of the six trees in each plot were either irrigated the day after harvest and irrigation was withheld from the other half of the trees for a period of five to eight days after harvest. Average daily sap flow after harvest was significant greater for water stressed trees compared to non-stressed treatments. Short-term yields were not significantly affected by harvest or irrigation treatment.

# IFAS Citrus Initiative MH Annual Progress Report 2010-11

Investigators: Dr. Tom Burks

Priority Areas Addressed: Machine Enhancements: Catch-frame/recovery rate improvements

Problem Statement: In recent years, mass harvesting fruit removal efficiency has been reported up to 95%, while the catch frame recovery efficiency has been reported between 88% and 92%. In recent grower observations, noted by Roka, catch frame efficiencies have been dropping into the low 80%, and in some cases even below 80%. The potential reasons for catch frame losses are numerous.

a. Misalignment of forward/reverse synchronization of left and right vehicles
b. In/out gap between catch frame seal and tree trunks on either side
c. Vertical misalignment of catch frame seals due to grove terrain, especially considering the bed-top and swell-bottom elevation differences.
d. The effectiveness of the fish-scale system employed to seal tree trunk

Accomplishments: The specific accomplishment for 2010/2011 were the following:

1) The design concepts developed in 09/10 have been further modeled and developed for a new catch frame closure system and frame position control. A laboratory scaled prototype of the new catch frame system was developed to demonstrate the concept. The concept consists of a new closure material which should be more compliant to the tree trunk, and a three section micro-adjustment which improves closure around the tree, while still protecting resets. The prototype was fabricated and tested under laboratory conditions. A PLC based controller was developed and implemented with sensors to detect mock tree presence and control the adaptable catch frame bed. Experimental results demonstrated feasibility although at laboratory scale and conditions.

2) Further advances in autonomous guidance were pursued to enable machinery synchronization and navigation in the citrus alleyway. We have developed and tested a migrateable auto-guidance control architecture that could be adapted to a broad range of applications. We have also worked on development of improved end of row turning approaches.

Gaps in the Current Programs Progress: Due to several factors, the prototype development has been hindered and limited to laboratory scale. These are partially due to funding limitations from last year's budget cuts, which limited progress, and unexpected development delays due to complexity of solving the design problem. We built and tested a scaled version of our design concept that we have demonstrated potential at laboratory scale. Without sufficient resources and the cooperation of OXBO, we are not able to build a functional testable full scale prototype.

Next Steps in Development; **Any future research would be dependent upon the availability of funding, which we have been told is not available for these topics.** Assuming funding were to become available to continue research, I would propose the following next steps.

1) The autonomous guidance systems has been developed for in-row navigation and end of row turning for single vehicle systems with good success at this stage. However, the next step is synchronized vehicle control. Past efforts have attempted to use under canopy laser sensor handshaking with moderate success. I believe that a better approach is to use RF transmitters over the top to establish master-slave along row following. We also propose a trunk and canopy sensing approach to maintain lateral vehicle position. In this next phase we propose to develop and test this approach. The final scope will be dependent on funding availability.

2) We now propose to develop a scaled and fully functional prototype to demonstrate performance under scaled and controlled field conditions. This prototype will allow us to further test various aspects of the design, in order to further demonstrate feasibility and test reliability and catch frame effectiveness under controlled field conditions. This effort would consist of development of the catch frame mechanical framework, actuators, and controls for a mockup field condition. Once fabricated and assembled, testing will be conducted using simulated harvesting conditions to evaluate the efficiency of the catch frame concepts. Design modifications will be made along the way to improve performance.

Publications Related to Funding


Han, S., Burks, T.F. 2011. Image Processing based 3D Reconstruction of a Citrus Canopy. (ready to submit)

Han, S., Burks, T.F. 2011. Multiple Layered Hierarchical Feature Tracking for Grove Scene. (ready to submit)

Jayaraman, V., Burks, T.F., Ho, J., Bulanon, D.M. 2011. Three Dimensional Mapping of Citrus Fruits in the Canopy using Computer Vision. (ready to submit)

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# IFAS Citrus Initiative MH Annual Progress Report 2010-11

Title of the subproject: Abscission management and managing abscission agent repository.