IFAS Citrus Initiative
Research and/or Extension 2009-10

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 2009/2010 were the following:

1) The design concepts developed in 08/09 have been further modeled and developed for a new catch frame closure system and the frame position control. A scaled prototype of the new catch frame system is being 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 improve closures around the tree, while still protecting resets.

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 and will be proving performance by end of research year.

Gaps in the Current Programs Progress: Due to several factors, the prototype development has been hindered. 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 now have a design concept that we think has potential, but without sufficient resources, we are not able to build a functional testable full scale prototype.

Next Steps in Development; To some extent the next steps in this research will be dependent upon the available funding. Assuming that sufficient funding is available to continue research, we 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. We 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 full scale, fully functional prototype to demonstrate and test catch frame performance under laboratory conditions. This prototype will allow us to test various aspects of the design, in order to further demonstrate feasibility and test reliability and catch frame effectiveness under laboratory conditions. This effort will consist of development of the catch frame mechanical framework, actuators, and controls. 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. At the end of this funding cycle, we plan to have a functional full scale prototype.

Publications Related to Funding

Mehta, S.S., T. F. Burks, W. E. Dixon. 2010. Target Reconstruction Based Visual Servo Control for Autonomous Citrus Harvesting. *Journal of Intelligent Service Robotics: Special Issue on Agricultural Robotics*, submitted 2/7/10.

Bulanon, D M, Burks, T F, Alchanatis, V. 2010. A Multispectral Imaging Analysis for Enhancing Citrus Fruit Detection. Environmental Control in Biology (in press - to be published in Vol.48, No.2 June 2010)

Subramanian, V., T.F. Burks, and W.E. Dixon. 2009. Sensor Fusion Using Fuzzy Logic Enhanced Kalman Filter For Autonomous Vehicle Guidance in Citrus Groves. *Transactions of ASABE* 52(5) 1-12.
Hannan M; Burks T F; Bulanon D M.2009. A Machine Vision Algorithm for Orange Fruit Detection. *The CIGR Ejournal.* Manuscript 1281. Vol. XI. December 2009.

Bulanon, D M; Burks T F; Alchanatis V. 2009. Fruit Visibility Analysis for Citrus Harvesting. *Transactions of the ASABE* 52(1): 277-283

Conference Papers and Presentations

Subbiah, Sundar; Burks. T.F. 2010 Control Architecture for Autonomous Agricultural Machinery. 2010 ASABE Annual International Meeting, Pittsburg, PA, June 20-23, 2010. Conference Paper 1008885.

Han, Sanghoon; Burks. T.F. 2010 Multilayered Active Mesh Tracking for Grove Scene. 2010 ASABE Annual International Meeting, Pittsburg, PA, June 20-23, 2010. Conference Paper 1008886.

Burks, T. F. 2009. Development of Autonomous Navigation For Citrus Groves using Vision and Ladar. 2009 ASABE Annual International Meeting, Reno, NV. June 21-24, 2009. (Invited Panelist Presentation).

IFAS Citrus Initiative
Annual Research and Extension Final Progress Report 2009-10
Mechanical Harvesting and Abscission: Machine Enhancement

Investigator:

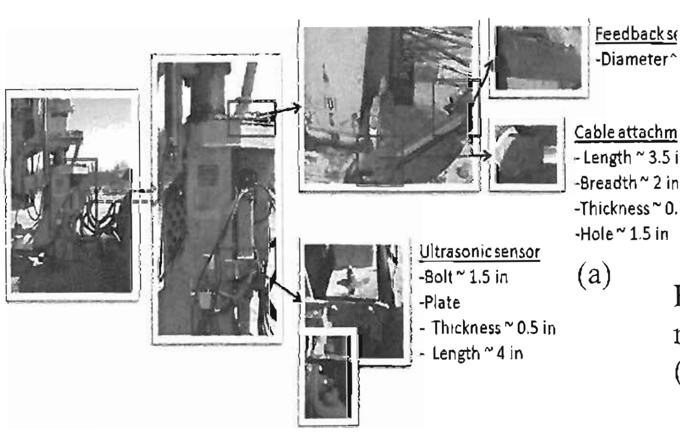
PI – Reza Ehsani, Agricultural & Biological Eng., University of Florida
Co-PIs – Won Suk Lee, Agricultural & Biological Eng., University of Florida

Objective(s) Pursued (Priority Topics):

1. To design and develop a rugged and cost-effective canopy measurement and control system to adjust the penetration of tree shaking tines into the tree canopy.
2. To develop an analytical model that can be used for optimal shaking of tree canopy based on the canopy volume.
3. Design and develop a pull-behind trash removal system.

Detailed Accomplishments in 2009-10:

1) **Design and development of canopy measurement and control system**:
A low-cost tine movement controller was developed to control the movement of the tines of the tractor drawn canopy shaker (TDCS). The goal was to reduce the time required for adjusting the amplitude of the shaker (for tine control) and further automating the process. The controller controls the tines based on the distance measurement. Our preliminary experiments on tine control (during June, 2009) indicated few challenges, some of which are: fast movement of tines causing safety concerns, and placement of Lidar sensor among the tines limiting its application, feedback mechanism and error in distance estimation due to vehicle vibration. Currently, a new control system has been developed that will address these concerns, and will further improve the control and operation of the shaker tines. In advancement to the previous controller, a SICK ultrasonic sensor was used for the distance measurement due to its ease in operation and cost-effectiveness. In addition, the controller (Fig. 1) has been customized to receive a threshold distance with specified tolerance that need to be maintained by the sensor from canopy edge. The sensor placed in the non-moving part of the tractor.



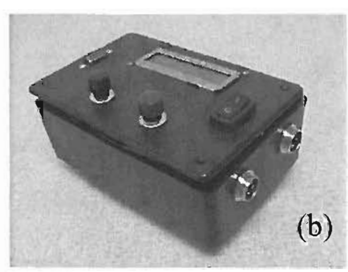


Figure 1. (a) Sensor mounting locations and (b) the controller.

The digital output from the controller (PIC18F458) has been set such that it can control the tines by communicating with the OXBO system (manual tine controller) directly. A feedback sensor system has also been incorporated to collect the distance of tine movement to offer further control. As a part of this objective a controller has also been developed and in place for field testing. The SICK UM30-214113 ultrasonic sensor and the ASM Cable Positioning sensor were attached to the analog input pins of the PIC. The program for this automation was written in BASIC and was executed on the PIC18F458 controller. The controller with the sensor systems (Fig. 1) will be incorporated in a real harvesting machine and field-tested in first week of June, 2010.

2) Develop an analytical model and determine the optimal shaking frequency of the tree canopy

An analytical model with a simulation framework based on finite element methods was developed and validated with field-experiments. The results indicated that the analytical model could predict ~60% variations in acceleration values experienced by the tree. The model could determine the accelerations in the tree structure for different boundary conditions (machine parameters). Since shaking frequency is an important parameter, it has been optimized using the model. At present, the trees are shaken with a fixed frequency of around 200 counts per minute (cpm) in the field. A series of five simulations with fixed shaking frequency (between 155 cpm and 255 cpm, 30s time duration) were performed. It was found that different parts of the tree attained their maximum values of total-acceleration at different frequencies. Therefore, for all parts of a tree to experience their maximum acceleration, each tree must be shaken through a range of frequencies (variable shaking frequency). After establishing that variable frequency is better that fixed frequency shaking, the objective was to determine the best frequency range. For this, two simulations with variable shaking frequencies (150 to 250 cpm and 65 to 165 cpm) were performed. As expected, the total acceleration values were in the same range as in fixed frequency shaking for 150-250 cpm variable frequency simulation. The simulation of 65-165 cpm variable shaking frequency indicated that the total acceleration values experienced by the trees were significantly higher than those during 150 -250 cpm variable shaking. It is possible that 65-165 cpm could be the resonant frequency range of the trees. However, in field conditions, owing to complex loading conditions and damping due to the leaves, this effect may be less pronounced. More field experiments are required before establishing that 65-165 cpm variable frequency is the optimal shaking parameter for tree canopies.

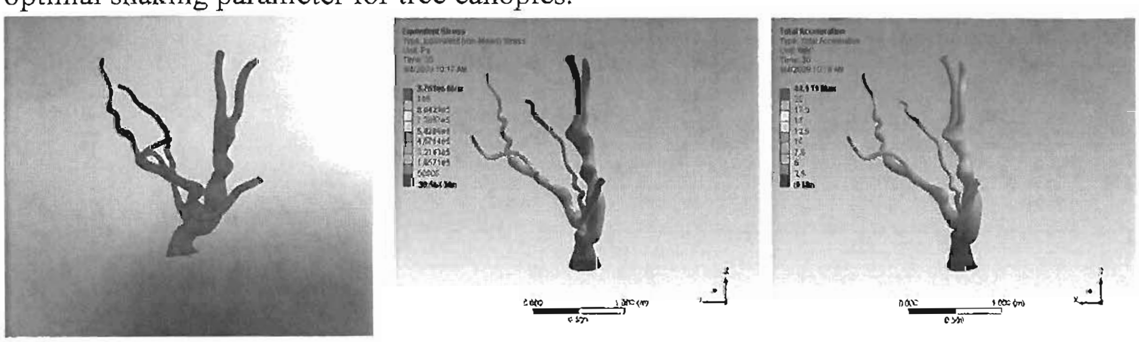


Figure 3. (a) Model of a tree, (b) stress districution, and (c) acceleration distribution

2) **Design and develop a pull-behind trash removal system**:

A pull behind platform with trash removal ability and fruit cleaning system was designed and built for mechanical harvesters. The overall system consisted of a pinch cleaner, blower, and yield monitors that aids in cleaning and removal of trash, and yield estimation during the mechanical harvesting process. This system has the ability to clean the entire fruit load from a hauling "goat truck" and completely remove all non-fruit trash. In addition, the system is also capable of measuring the amount of trash and yield (based on mass-flow). In addition to these components, an extended de-stemmer was also designed and fabricated to be used with mechanical harvesters. Preliminary studies showed that the extended de-stemmer has a removal efficiency of 50% for petioles less than 2 inches and 86% for petioles longer than 2 inches.

The systems (Fig. 3) have recently been field-tested in the Lykes grove in Ft. Basinger (18-20th, May 2010) to evaluate their performance. It was observed that the de-trasher eliminated all the trash from the mechanically harvested citrus fruits thus obtaining a cleaner fruit load. The extended de-stemmer removed about 4% more trash (by weight) than the regular de-stemmer. However, further experiments are needed to validate these findings. It is anticipated higher trash removal efficiency can be achieved.

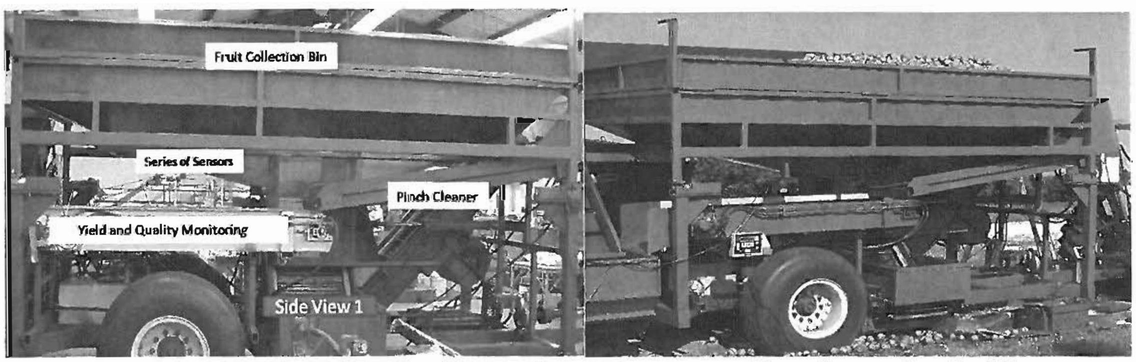


Figure 3. Platform attached to the tractor for various operations in mechanical harvester.

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

The recent citrus black spot (CBS) disease outbreak has required that trucks carrying fruit be tarped. Since the new pull-behind trash removal machine can completely remove leaves from the load of fruit, tarping is not needed. Tarping is used to prevent CBS-infected leaves from spreading to other groves during transit, and is a expensive and potentially hazardous process.

<u>Areas where progress didn't meet expectations</u>:

- An efficient 3D model that better simulates the harvesting process is needed.
- The off-road terrain conditions affect the movement of the tines making the process more challenging.

<u>Impact of accomplishments towards overall goals of funding</u>:

The developed mechanical systems, machine enhancement project, and simulation studies can provide the following benefits:

- The controller for tine distance and movement adjustment can help in rapid control and operation of mechanical harvester, especially the shakers, reduce tree injuries, and ease the operator job.

- The simulation program for evaluating shaking characteristics can assist in developing better shaking and fruit removal mechanism.
- The pull behind platform can aid in cleaning the trash and fruits associated with mechanical harvesting, and reduce processing costs.

The overall benefits of these systems would be an effective management practice during mechanical harvesting.

Presentations associated with 2009-10 efforts:

Ehsani, R. (Presenter) "Current Machinery and Machine Enhancement for Mechanical Harvesting of Citrus ", Immokalee, FL. Dec. 8, 2009.

Ehsani, R. (Presenter) "Current Machinery and Machine Enhancement for Mechanical Harvesting of Citrus ", Ft. Pierce, FL. Sep. 24, 2009.

Ehsani, R. (Presenter) "Automation and Mechanical Harvesting for Fruit Production", University of Kyoto, Kyoto, Japan, July 14, 2009.

Publications from 2009-10 efforts:

Savary, S. K. J. U. (2009). Study of the force distribution in the citrus canopy during harvest using continuous canopy shaker. Unpublished master's thesis. University Of Florida.

Refereed Publications:

Savary, S. K. J. U. , R. Ehsani, J. K. Schueller, B. P. Rajaraman Mishra. Simulation study of citrus tree canopy motion during harvesting using a canopy shaker. 21 pages. Transactions of ASABE. (Submitted March 2010)

Savary, S. K. J. U. , R. Ehsani, M. Salyani, and M.A. Hebel. Study of force distribution in citrus tree canopy during harvesting using a canopy shaker. 21 pages. Journal of Computers and Electronics in Agriculture. (Submitted May 2010)

Ehsani, R. and D. Karimi. Yield Monitors for Specialty Crops. 14 pages. Special issue of the Journal of Computer and Electronic in Agriculture. (Submitted August 2009)

Ehsani, R. Mechanization and Productivity Aides for Crop Production and Harvesting: The Status of Mechanization for Citrus. 10 pages. Special issue of the Journal of Computers and Electronics in Agriculture. (Submitted March 2009).

Bansal, R., W.S. Lee, R. Shankar, and R. Ehsani. Automated trash estimation in a citrus canopy shake and catch harvester using machine vision. 36 Pages. Journal of Computers and Electronics in Agriculture.

Non-refereed Publications:

Ehsani, R., and S. Udumala. 2010. Mechanical harvesting of citrus. Resource. May/June: pp. 4-6.

Maja, J. M. and R. Ehsani. 2009. Development of a new load-cell based yield monitor for citrus. Proceedings of the Symposium on the Applications of Precision Agriculture for Fruits and Vegetables International Conference. ISHS, Acta Horticulturae 824: 267-274.

Patil, R., W. S. Lee, R. Shankar and R. Ehsani. 2009. Detection and Elimination of Trash using Machine Vision and Extended De-Stemmer for a Citrus Canopy Shake and Catch Harvester. Proceedings of the American Society of Agricultural Engineers (Florida Section Meeting). Daytona Beach, FL. FASAE Paper No. FL09-129.

Ehsani, R. 2009. Maximizing field efficiency of farm machinery using GPS data. Citrus Industry. July: pp. 10-11.

Next steps:

- However, there is a need to investigate a simulation framework for evaluating the effect of different machine parameters.
- Studies are needed to determine how existing machines should be changed to better work with the abscission compounds.
- Extensive field tests to further evaluate the performance of extended de-stemmer and de-trasher unit.
- Study the effect of factors such forward speed, shaking frequency, variety, maturity level, and grove condition on the amount of trash.
- Developing alternative less expensive and simpler harvesting machines for harvesting with citrus fruit with abscission compounds.