IFAS Citrus Initiative
Annual Research and Extension Progress Report 2006-07
Mechanical Harvesting and Abscission

Machine Enhancements and Improvements

Investigator and Contributors:

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Objectives pursued:

Objective 1: Yield monitoring system for mechanical harvesters
Objective 2: Improvement of canopy shaking mechanism to reduce tree injuries
Objective 3: Catch-frame/recovery rate improvements

Objective 1: Yield Monitoring System for Mechanical Harvesters

Detailed accomplishments in 2006-07

The ultimate goal of this study was to develop a yield monitoring system (YMS) for citrus mechanical harvesting machines. A yield monitoring system can measure yield and produces a yield variability map and is highly desirable by citrus growers. Currently, there is no commercially available yield monitor for citrus harvesting machines. The major component of a yield monitoring system is a Mass Flow Sensing (MFS) system which measures the citrus fruit mass every second as they are harvested by citrus harvesting machines. In this project, three methods of mass flow measurement were compared to select the best method for further yield monitor development. These methods were; 1) Load cell based MFS, 2) Image-based and volume-based MFS, 3) Optical-based counting/sizing MFS. The following are the results for each system.

Load cell based MFS system

Load cell based MFS system:

A new load cell based MSF was developed which consisted of two load cells, a signal conditioning and processing unit, wireless communication, and a data storage unit. The system was installed on an OXBO 3220 Canopy Shaker with Catch Frame for field testing. The MSF was evaluated under static and dynamic conditions in the Lykes Grove in Ft. Basinger, FL. The static test has produced very encouraging results with excellent linear output signal corresponding to the load weight with the following linear calibration model:

The signal (mV) = 43.966*Weight (lb) + 49.018 with a coefficient of determination (R^2) of 0.995.

Several rounds of field tests were conducted during actual harvesting by the machine using the calibration model from the static test. The trend of predicted weight against the true weight also showed an encouraging trend with error as low as - 0.64% in a run. Due to lack of an accurate scale in field, there were some issues in measuring the true weight (actual weight) of harvested fruits during the field tests to compare the measured weight vs. true weight. To address this issue, a new scale was purchased to collect actual fruit weight values. Based on the field results, a new version of the load cell- based MSF system was developed using four load cells and a special carbon fiber plate which is expected to improve the results even more. Overall, this MFS system is very promising. Ease of installation and maintenance, low-cost, low weight, ruggedness and durability, and acceptable error (less than 5%) were among the advantages of this sensor. This MFS system was selected as the best candidate for further development.

Image-based and volume-based MFS

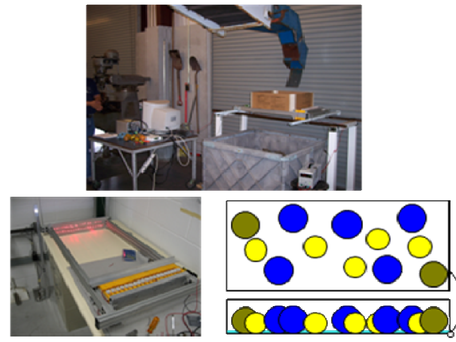
A machine vision based citrus yield mapping and fruit quality inspection system was developed. The system consisted of a 3CCD camera, four halogen lamps, a DGPS receiver, an encoder and a laptop computer. A total of 3,653 images were taken during an experiment on the test bench at the Citrus Research and Education Center (CREC), Lake Alfred, Florida and 703 images were used for analysis. The system was also tested on a commercial canopy shake and catch harvester at the Lykes Grove located in Fort Basinger, FL. A total of 773 images were acquired as well. Fruit weight was measured in 14 test trials of image acquisitions during the test bench experiment as well as in two test trials of image acquisitions during a field trial with a commercial canopy shake and catch harvester. An image processing algorithm that could identify and inspect fruit qualities was developed. The number of fruit and total fruit areas were measured from the sets of color images using the developed algorithm. Finally, the number of citrus fruit identified by the image processing algorithm during the test bench experiment was compared against actual fruit weight. The Calibration coefficient of determination, R^2, was 0.962. For the canopy shake and catch harvester experiment, the number of fruit in a total of 60 images was counted manually and was compared with the computer vision algorithm count. The test yielded an R^2 of 0.891 for actual and estimated number of fruit. In spite of reasonably good results under static conditions, this system was not selected for further development due to the cost, complexity, size and weight.

Image-based and volume-based MFS system

Optical-based counting/sizing MFS

A new Time-of-Flight sensor was developed to measure the flow of citrus fruits in real time.

This device consists of two photo interruption layers, where each layer contained 20 laser beams. A major advantage of using laser light is the absence of defocusing problems that are present when non-coherent light sources are used. A disadvantage of laser light is the potential of erroneous signals due to vibrations. This problem was dealt with by mounting the laser beam generators and receivers in a very rigid frame. The laser beams were coupled with optical receivers, which were connected in a logical AND function. The flow of citrus fruits was regarded as a count per time unit. A complication in the flow measurement of citrus fruits lies in the fact that many fruits interrupt the laser grids simultaneously. This implies that they cannot be counted individually, and therefore a theoretical method was needed to count them in a statistical sense. This method was developed in cooperation with statistician Dr. Kate Crespi from UCLA. The method that is used is counterintuitive: instead of using the measured times during passages of citrus fruit clumps; the flow density information is retrieved from the spacing times among the clumps. This method is justified if the flow forms a statistical Poisson process. The total experiment time can be simply measured by adding all clumps and spacing times. By multiplying the total experiment time in seconds by the flow density in fruits/second, the total number of fruits passing during the experiment can be computed. The sensor also measures the average diameter of the fruits, which allows for translating the fruit density in number of fruits per time unit into a mass per time unit. Currently, tests are being carried out to measure the flow of citrus fruit in an experimental arrangement. The first step is to validate the Poisson driven arrival assumption. Secondly, tests are carried out where large numbers of fruits are dropped from a funnel, which has been shown to cause a Poisson flow in similar test with smaller particles. After these tests are complete successfully, the sensor will be tested on a working harvester. Although this is a very innovative method of measuring mass flow and can potentially eliminate the calibration issues, this method was not selected for further development mainly due to that fact that it is still in the initial stages of development and may not be ready soon enough to answer immediate need of the growers.



Optical-based counting/sizing MFS system

Areas where progress exceeded expectations:

Development of the second version of the load-cell based MFS was on the top of our list. If we could get a specially ordered carbon fiber plate on time, we could have gotten some field data with the new system. However, the carbon fiber plate didn't arrive before the end of harvesting season.

Areas where progress didn't meet expectations:

In our proposed plan of work, we proposed to test a commercially available grape yield monitor system that was retrofitted to a citrus mechanical harvester. However, difficulty in installation of that system and failure of the system early in the season prevent us from further pursuing this goal. In addition, at the first year of this study we used a different system for measuring yield for trunk shaker mechanical harvesting machine. We didn't continue developing that system because we believe the newest version of the load cell based MFS can be used for both canopy shaker as well truck shaker systems.

Impact of accomplishments towards overall goals:

Based on the results of this study, we were able to choose the best mass flow sensing system for the citrus mechanical harvesting machine and now we are ready to develop a complete yield monitoring system and collect a full year of yield data for a pair of citrus mechanical harvesting machines.

Presentations associated with 2006-07 efforts:

- Ganesh Bora, Reza Ehsani, Hala Chaoui. 2007. Development of a Yield Monitoring System for Citrus Trunk Shake and Catch. ASABE paper no. 071047. St. Joseph, Michigan.
- Min Min, Reza Ehsani, Ganesh Bora. 2007. Development of a Mass Flow Rate Sensing System for Citrus Mechanical Harvester. ASABE paper no. 071048. St. Joseph, Michigan.
- Chinchuluun, R., W. S. Lee, and R. Ehsani. 2007. Citrus yield mapping system on a canopy shake and catch harvester. ASABE Paper No. 073050. St. Joseph, Mich.: ASABE.

Publications from 2006-07 efforts:

- Ganesh Bora, Reza Ehsani, Hala Chaoui. 2007. Development of a Yield Monitoring System for Citrus Trunk Shake and Catch. ASABE paper no. 071047. St. Joseph, Michigan.
- Min Min, Reza Ehsani, Ganesh Bora. 2007. Development of a Mass Flow Rate Sensing System for Citrus Mechanical Harvester. ASABE paper no. 071048. St. Joseph, Michigan.
- Chinchuluun, R., W. S. Lee, and R. Ehsani. 2007. Citrus yield mapping system on a canopy shake and catch harvester. (Under preparation to be submitted for publication in the ASABE Journals.)

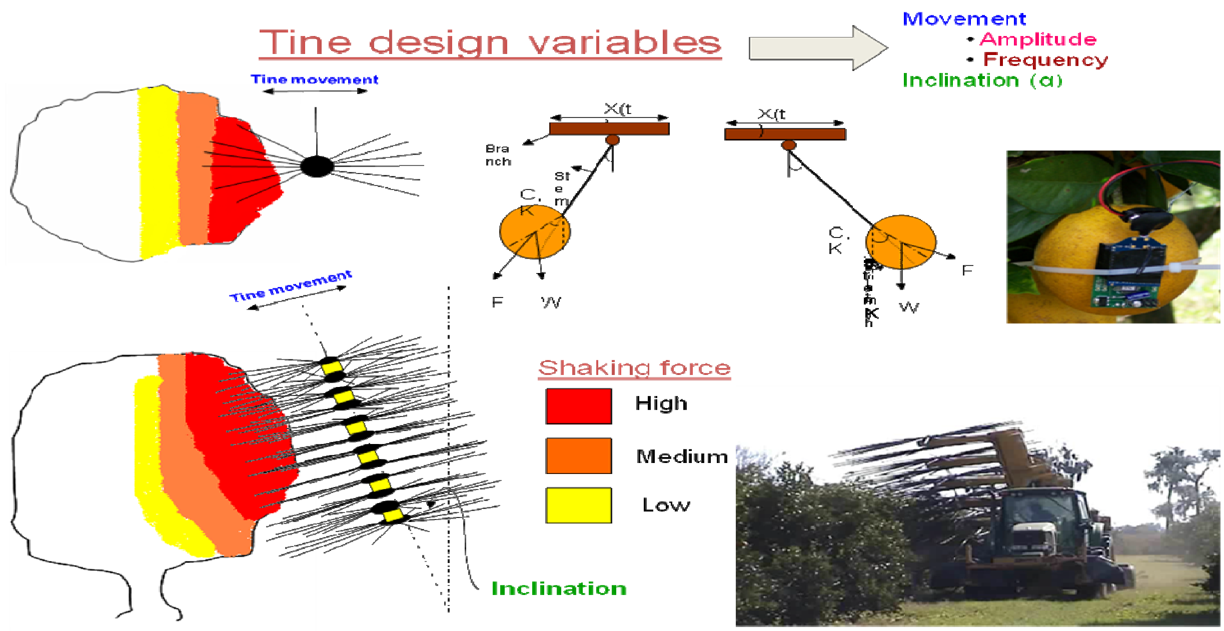
Next steps:

The load-cell based mass flow sensing system has been chosen for further yield monitoring development. A new improved version of a complete yield monitoring system (including two mass flow sensors, wireless communication, and data storage system) will be developed and will be installed on the citrus mechanical harvesting machine to collect field data for a complete harvesting season. The developed system is also potentially patentable. We will discuss with the Office of Technology Transfer for taking the necessary steps in this regard.

Objective 2: Improvement of canopy shaking mechanism to reduce tree injuries

Detailed Accomplishments in 2006-07

Canopy shaking mechanical harvesting machines are becoming popular in Florida. Many design factors in developing these machines such as shape of tine, number and length of the vibrating tines, the angle of tines with respect to tree canopy, forward speed, shaking frequency, and displacement amplitude have been selected through a trial and error process. To improve the percent fruit removal and reduce tree injury, it is necessary to really understand how the fruit removal process happens when the machine interacts with the tree. To quantify the vibration fruit removal force, a multi-node ZigBee-based wireless sensor was developed that was able to measure the fruit acceleration in 3-D simultaneously at several points on the canopy. Field experiments were conducted in 4 groves, two with Hamlin and two with Valencia. In one field of the Valencia variety, test was conducted on a tree treated with abscission agents and on another untreated tree in the same row of the grove. The developed sensor was rugged and worked well under field conditions. The results indicated that the amount of actual fruit removal force by the canopy shaker is about twice that of the current method of measuring fruit removal force that can be seen in the literature. The force experienced by the fruit is dependent on the location of fruit on the canopy. This could be caused by the radial formation of the tines. In addition to maximum force, duration in which the force is applied can affect the fruit removal as it causes fatigue. Force requirement for fruit removal decreases as the season progress. As expected, the fruit treated with abscission agents were removed easily and with less force. However, it was found that in addition to natural variability of fruit removal force in the tree canopy, mechanical harvesting machine also are not applying uniform fruit removal force. This information would allow modification and improvement of shaking mechanisms to reduce tree injuries which would help to maintain the health condition of citrus groves, decrease the chance of canker infection (by reducing the tree injury or plant material removal), and decrease machine downtime increasing harvesting efficiency.



Areas where progress exceeded expectations:

N/A

Areas where progress didn't meet expectations:

We didn't develop new sets of tines as it was suggested in the plan of work. Our initial data suggested that the factors that affect the fruit removal are more complicated than what we initially thought. We believe more data needs to be collected before making changes in the tine.

Impact of accomplishments towards overall goals:

The developed wireless data collection technique proved to be a useful tool in studying the fruit removal process with citrus mechanical harvesting machines. This equipment will help us to design a more complete experimental design and evaluate the factors that influence fruit removal and eventually help us to develop a better fruit removal system.

Presentations associated with 2006-07 efforts:

- R. Ehsani, M. Hebel, G. Bora and K. Lee. 2007. In-situ Measurement of the Actual Detachment Force of Oranges Harvested by a Canopy Shaker Harvesting Machine. Proceedings of Florida State Horticultural Society Annual Conference.

Publications from 2006-07 efforts:

- R. Ehsani, M. Hebel, G. Bora and K. Lee. 2007. In-situ Measurement of the Actual Detachment Force of Oranges Harvested by a Canopy Shaker Harvesting Machine. Under preparation to be submitted to Computers and Electronics in Agriculture.

Next steps:

To use the developed mesh network sensor in a more comprehensive test to evaluate the effect of forward speed, tine angle, and shaking frequency on the fruit remove maximum force and force distribution.

Objective 3: Catch-frame / recovery rate improvements

Detailed accomplishments:

During citrus harvesting, two canopy shake and catch harvesting machines work in pairs, one on each side of the row of citrus trees necessitating synchronization of their travel speed and steering. Unreliable synchronization causes inefficiency in the catching system. This degrades the capability of the citrus harvesting system. Therefore, the overall goal of this objective was to develop a control system for synchronizing the forward movement and steering of two test vehicles (master and slave) driving in a parallel path. The control system mounted on the slave vehicle was composed of a laser scanner for distance measurement between the master and slave, a liner actuator for adjusting a travel speed, a DC brush motor with a rotating armature for adjusting a steering angle, a LabVIEW control program with incorporated PID controllers, and a computer. Two PVC pipes were mounted on the front and rear side of the master vehicle as a pole indicator for the laser scanner. An algorithm for calculating the leading distance and heading angle difference between the master and slave and generating the new trajectory for the slave from the distance measurements of the laser scanner was developed. The leading distance and heading angle difference obtained were used as input parameters for the PID controller and recorded as control errors for the travel speed and steering controls, respectively. The experiments for testing the performance of the control system were conducted on straight and trapezoidal paths with a travel speed of 1 m/sec. The root-mean-square (RMS) errors of the leading distance and heading angle difference on the straight path were 51 cm and 7°, respectively; the RMS errors on the trapezoidal paths were 52 cm and 11°, respectively.

Areas where progress exceeded expectations:

There is very little published information on characteristics and performance of these laser scanners that are used in this study. Thus, an additional research for comparing the performances of the SICK LMS200 and the Hokuyo URG-04LX laser scanners in measurement drift over time, the effect of material and color on measurement accuracy, and the ability to map different surface patterns was conducted. This research result was submitted to be published in the journal of *Computers and Electronics in Agriculture.*

Areas where progress didn't meet expectations:

The progress on catch-frame/recovery rate improvements objective in this fiscal year met all expectations.

Impact of accomplishments towards overall goals of funding:

It is expected that the developed control system will contribute to improving catch-frame/recovery rate when the system is mounted on the real canopy shake mechanical harvesting machine.

Presentations associated with efforts:

- Lee, K.H., R. Ehsani, and J. Schueller. 2006. Real-time movement synchronization of a pair of vehicles. ASABE International Meeting, Portland, Oregon.
- Lee, K.H., R. Ehsani, and J. Schueller. 2007. A control system for movement synchronization of two vehicles in parallel. ASABE International Meeting, Minneapolis, Minnesota.

Publications from efforts:

- Lee, K.H., R. Ehsani, and J. Schueller. 2007. Forward movement synchronization of two vehicles in parallel using a laser scanner. *Applied Engineering in Agriculture* (in review).
- Lee, K.H., and R. Ehsani. 2007. Comparison of two 2-D laser scanners for sensing object distances, shapes, and surface patterns. *Computers and Electronics in Agriculture* (accepted).

Next steps:

The possibility that the technology developed in this study can be transferred to OXBO, a manufacturer of the canopy shake mechanical harvesting machine, will be discussed.