IFAS Citrus Initiative
Annual Research and Extension Progress Report 2008-09
Mechanical Harvesting and Abscission

Investigator:
PI – Tom Burks
Co-PIs – Fritz Roka and Reza Eshani

Objective(s) Pursued (Priority Topics):
Machine enhancements:
1) Enabling 24 Hr Harvesting
2) Improvement of Catch Frame Efficiency

Detailed Accomplishments in 2008-09:

1) Enabling 24 Hr Harvesting: The most important issues in deciding whether to extend the current work days are the issue of machine utilization and load allocations. Dr. Roka has been investigating the significance of load allocations and whether it is possible for the industry to adopt a more mechanical harvesting friendly approach to load allocations. Meanwhile, we have been seeking to develop a framework for modeling machine utilization that could be used to analyze different harvesting scenarios. That is, create a modeling environment that would allow the user to select various different combinations of harvesting machines with user selected efficiencies and harvesting rates, number of goats, grove layout and roadside pickup location, mean time to breakdown, and other performance information. The work thus far has focused on the trunk-shake-catch system since it is the most complex modeling problem. Once this system is modeled it would be relatively straightforward to extend the model to a canopy-shake-catch system. The following specific points of emphasis have been pursued.
   a. Development of User Interface for Harvesting Model
   b. Data set extraction from video clips of TS&C system
   c. Model development using Excel based simulation language
   d. Fundamental model testing

As a result of this work, it has been determined that the model works for simple scenarios. However, due to limited data availability for several of the stochastic processes included in the model, it has become evident that additional time and motion data will be required to move the model forward.

2) Improvement in Catch Frame Efficiency: A recurring issue during the development of Canopy-Shake-Catch mechanical harvesting systems has been the efficiency of the catch frames for collecting fruit removed from the tree by the shaking system. In recent years harvesting fruit removal efficiency has been reported around 95%, while the catch frame recovery efficiency has been reported between 88% and 92%. Obviously whatever percentage of the fruit that remains on the tree or ground either has to be gleaned (adds labor cost), or abandoned (lost
produce). In either case, the grower’s profits are reduced substantially. 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 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, or hilly terrain on the ridge.
d. The effectiveness of the fish-scale system employed to seal tree trunk

In recent conversations with OXBO to discuss the problem, they identified some additional reasons for the recent drop in catch frame efficiency. First, due to the advent of citrus greening there has been an increase in the number of tree resets. Operators are very careful to avoid taking out a reset with the impact of the fish-scale hitting the trunk, and consequently will slightly open the catch frame when they encounter a reset. This also introduces the potential for reset mis-alignment with in the row which requires an even larger opening of the frame to avoid hitting the reset tree. In addition, as yields have been dropping due to HLB, operators have been speeding up in an attempt to maintain the same harvested fruit/hr. Therefore, the catch frame is not remaining under a given tree as long as before when operating at slower speeds. This results in some of the fruit not reaching the catch frame before the fruit moves out from under the tree and falls to the ground. Neither of these conditions have been experimental confirmed, but seem to be reasonable causes for the recent drop in catch frame efficiency. It would be worthwhile to plan a rigorous study to determine whether these are in fact additional causes of catch frame efficiency reduction.

In the past, an effort was made to improve catch frame efficiency by introducing an automated speed control system that attempted to synchronize the within row forward/reverse position of the left and right CSC machines. Later an attempt was made to solve the problem using autonomous steering guidance and trunk detection sensors to maintain a closed gap between catch frames. Neither of these approaches were complete solutions due to the other factors mentioned above. It is now believed that a significant redesign of the catch frame, it’s control, along with autonomous guidance is going to be necessary. There is not a simple fix to this problem. In order to improve the catch frame efficiency a overall systems solution must be developed that address all the reasons for catch frame separation.

During this funding year we have focused on three primary tasks:

a. Identify the cause of catch frame inefficiencies
b. Conducting a literature review of catch-frame technology
c. Development of model concepts for a systems-based solution

At this point, we believe that we have thoroughly addressed the first two objectives. We have developed a fundamental system concept in Solid Works
computer-aided design, which address the issues mentioned above and that will be the basis for the design stage development. We have discussed our conceptual ideas with OXBO and have received favorable feedback. They have indicated that at this time, they cannot actively pursue implementing our concept due to other R&D effort on CSC trash reduction. They did, however, strongly encourage us to move forward with concept development, design, and proof of concept. Due to intellectual property issues, we cannot go into further details of the actual design concepts until we have submitted a patent disclosure.

**Areas where progress exceeded expectations:**

1) **Enabling 24 Hr Harvesting:** We have developed a very convenient user interface for the Excel based simulation model. It gives the user a high level of control over the simulation parameters, and will provide useful statistics on the outcome of the harvesting scenario.

2) **Improvement of Catch Frame Efficiency:** When we initially started this topic, it was very uncertain what the issues were, and whether there were any straightforward solutions that could be pursued. As we explored the cause of the problems with efficiency, it became clear that there were in fact no easy fix solutions and therefore it was necessary to take a look at the whole system. We have been very pleased with the concepts that have been developed for redesigning the catch frame, fish-scale, and overall control of the machines with respect to improving the performance.

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

1) **Enabling 24 Hr Harvesting:** We had hoped that we could extract sufficient time and motion data from the video records of trunk shake and catch systems to build the model. We have currently used estimated T&M data to represent any simulation events where insufficient data was available. However, it is clear that we will not be able to finish the model development and validation, unless we are able to get more data from TS&C systems in operation. Unfortunately, there aren’t any TS&C systems operating in Florida that we can observe. The question remains whether it is possible to bring a unit back into operation to collect the missing data. This may be a stopping point until it is determined if TS&C has a niche market in the Florida Ridge area or not.

2) **Improvement of Catch Frame Efficiency:** In the absence of a simple alternative, the concepts that we are considering will require significant modification to the mechanical and control aspects of the CS&C machine’s fruit collection approach. This will likely result in significant development cost, which translates into an increased cost of machine systems. However, there does not seem to be any other way to significantly improve the catch frame performance without this type of systems solution approach.
Impact of accomplishments towards overall goals of funding:

1) **Enabling 24 Hr Harvesting:** We have the foundation of a good modeling package, but without the remaining data its usefulness in demonstrating the potential for TS&C’s contribution for small to mid-sized producers is at a standstill. We can move on now to modeling the CS&C system if deemed appropriate and then return to TS&C in the future when we can get more data from a system in operation.

2) **Improvement of Catch Frame Efficiency:** Although there may be approaches not yet discovered that can solve the catch frame efficiency problem, this complete systems-based solution holds the potential to dramatically improve catch frame fruit recovery. However, it will come at the cost of complexity which has some risks associated with it, and most likely additional cost to the equipment. Once perfected it could provide the dual machine harvesting system with a catch frame that can handle the non-uniform terrain, tree size and tree reset placement issues that have caused low catch efficiencies. It will also help solve the problem of operators driving the vehicles too fast by putting the vehicles on auto-pilot where the operator is taken out of control of vehicle speed.

**Presentations associated with 2008-09 efforts:** None

**Publications from 2008-09 efforts:**
Refereed: None
Non-refereed: None

**Next steps:**

1) **Enabling 24 Hr Harvesting:** We either need to get a TS&C system operational and collect the remaining data, or move on to modeling CS&C systems. We can’t go any further with TS&C without new data.

2) **Improvement of Catch Frame Efficiency:** There are three major development tasks that need to be implemented: 1) fish-scale and trunk closure redesign and control, 2) frame lift and extension control, 3) vehicle position and synchronization control. Each of these will require substantial development and testing. It is proposed that we would start with task 1 & 2, and then finish with task 3. These tasks are expected to require a minimum 2 year development period depending on funding availability. The design concepts will be further developed in the upcoming year, and a scaled prototype will be developed for task 1 and 2. These will later be adapted to an autonomous vehicle pair for testing a fully functional system.
Investigator:

PI – Ehsani, R., Citrus Research and Education Center, University of Florida

Objective(s) Pursued (Priority Topics):
Developing a yield monitoring system for mechanical harvesters.

a. To make minor improvements to the existing load cell based mass flow sensors that have been installed on the self propelled canopy shaking citrus mechanical harvesting machines during 2008-09.
b. To improve the computer program for the microprocessor unit so that it does not rely entirely on GPS signal to start collecting data.
c. To build a visual display unit that can provide information on the amount of fruit harvested to the operator.
d. To develop a back-up, alternate yield monitoring system that could easily be combined with the current system.
e. To develop a set of paradigms on how to fuse two or more different sensors that will report the same data.

Detailed Accomplishments in 2008-09:
The development of the yield monitoring system for citrus included the development of software and hardware components. During the phase of this development, different technologies and methods were investigated.

![Diagram of Yield Monitoring System](image)

New design was developed for the impact plate and two new impact sensors were also tested. The new design minimized the gap between the conveyor and also the gap on both sides. It also facilitates the installations and maintenance of
the impact plate as the whole plate is now attached on the metal frame beneath it. All the wiring for this new design is now located at the bottom of the plate with water-proof enclosure and used wireless transmission of data. This minimized the wires of the whole system as the system needs only two wires for the power. We believe the concept that is used in our latest design is patentable and we will soon disclose the details to the UF for patent application.

The program for the microprocessor unit installed in the unit was also updated. The stack size of the system is now monitored and whenever GPS is not available for a certain time, it uses an invalid GPS string to transfer the data while clearing the stack buffer at the same time. This solved the problem of stack overflow which we encountered last year.

We also developed a graphical user interface (GUI) for the yield monitor. GUI is a software that is installed on a small touch screen capable portable computer in front of the operator. GUI display provides yield information to the operator. It also stores all the raw and processed data in the computer for future use. The GUI interface has been developed in LabView® software from National Instruments. Using this interface, the operator can get information about cumulative and instantaneous yield in pounds and number of boxes. One of the nice features of this interface is the alarm system. When the citrus container exceeds its set capacity, the system alarms the operator that the current trailer has now reached its optimum load, thus, the new load should now be delivered to a new trailer.

![Figure 3. Yield monitoring system Graphical User Interface (GUI).]
A backup system for the impact plate yield monitoring utilizes multiple optical distance sensors placed at a certain distance above the conveyor belt. The distance sensors measure the citrus volume on the conveyor belt in real time. The preliminary laboratory test showed promising results and further test is needed to complete this part.

Developing paradigms to fuse together same data from different sensors is related to backup system described above and is actually the next step once a good sensing modality is found to complement the load cell based system. One of the approaches of combining the reported data from both impact plate and the distance sensors was to define weights based on the percentage error each of this system generates. Giving more weights to sensor that reported the least error. Unfortunately, we haven't tested these rules as the backup system needs further testing.

Extracting field efficiency information from yield data can provide valuable information for grove manager about their machine performance. For example, the amount of machine down time for each harvester can be determined and compared from year to year. It can also be used to compare the performance of machine operators and different harvesting crew. A stand alone computer program was developed to determine yield map data, field efficiency, machine capacities and field machine index from standard NMEA GPS strings and load cell data stored in the yield data. A block diagram of
the program is shown in figure 6. The implemented algorithm extracts position (latitude and longitude) and time/date stamps from yield data. Using these as input, the algorithm generates the following outputs.

- Numbers of data points
- Numbers of harvesting days
- Lat/Long map
- Moving points map
- Stopped Points map
- Turning points map
- Straight Points map
- Operation time
- Stopped time
- Turning time
- Effective time
- Total driven distance
- Total covered area
- Speed statistics
- Mass/voltage calibration
- Yield statistics
- Statistics for individual days

Figure 6. Program structure. Outputs are generated through one button click.

Areas where progress exceeded expectations:
Development of new impact plate was not a part of the proposed plan. This new system can be substantially reduce the cost of yield monitoring system and can be used for other specialty crops such carrot, potato and tomato as well.

Areas where progress didn’t meet expectations:
The paradigm to fuse together data from different sensors is being worked on as it needs the redundant yield monitoring system to be tested and ready for developing the rules for this paradigm.

Impact of accomplishments towards overall goals of funding:
Based on the results of this work, we developed a new design for the impact plate system that minimized the problems encountered. A GUI was also designed for the operator of the machine to monitor the real time information during harvest. A stand alone program was developed providing growers with an easy tool to visualize field and machine potentials to increase benefits and reduce cost.

Presentations associated with 2008-09 efforts:


Publications from 2008-09 efforts:

Refereed:


Non-refereed:

None

Next steps:

Field test of both systems:
We are proposing to install the new impact plate and the GUI system on mechanical harvester and run it for an entire year to assess its ruggedness and potential problems in running under harsh field environment.

Enhancements to the standalone post-processing program:
Future enhancements to the post-processing program would be to make the output file compatible with Google earth and other GIS software available and to develop an online reference database for mechanical citrus harvesting.
Investigator:
PI – Ehsani, R., Citrus Research and Education Center, University of Florida
Co-PIs – Burks, T., Agricultural & Bio. Eng., University of Florida

Objective(s) Pursued (Priority Topics):
Improve canopy shaking mechanism to reduce tree injury
Developing a variable rate tree canopy shaking system to reduce tree injury and improve fruit removal
a. To improve the laser measurement system that was developed last year (07-08).
b. To investigate the possibility of automatically adjusting the tine penetration distance and angle with respect to tree canopy using ultrasonic sensors.
c. To develop an analytical or experimental model that could adequately determine the best shaking parameters for a given citrus tree canopy size.
d. Mount the laser-scanning system and control unit on a real canopy shaking harvesting machine and conduct tests to determine the variables of the PID controller.

Detailed Accomplishments in 2008-09:
In order to reduce the injury to the tree and also to increase the fruit removal efficiency, it will be helpful to study the distribution of force in the citrus tree canopies. Field experiments were conducted on Late Navel variety. Three selected trees were defoliated and their smaller branches removed for the experiment. At least 3 branches per tree were attached with the accelerometers at intervals of 50 cm from the base of the tree. The branches were selected such that they were in different orientations. The trees were shaken at two different frequencies with each one being repeated three times. Apart from

Figure 1.Experimental setup.
citrus trees, the same experiment was conducted on two rectangular beams made of commercial lumber. Two accelerometers were also attached to the tines while doing the experiment on the beams to investigate the acceleration values on the tines.

The citrus tree branches were modeled as conical cantilever beams with distributed load. The model was created using SolidWorks® software. In order to create the 3D model, the measurements of the tree were taken at intervals of 10 cm along the branches where the accelerometers were installed for the experiment. For measurement of coordinates, the base of the tree was taken as origin with positive Z upwards and X-Y plane on the ground. For simulation of the tree behavior during harvesting process, the tree material properties were determined using experiments on wood blocks of the tree. The Young’s, Bulk and Shear modulus were determined experimentally along with the density of the material. Validation of the finite element model is being done. The data from the experiments conducted was processed so as to extract the acceleration at various points on the tree. The force on the tree at different locations due to the contact with tines is being modeled. The acceleration values at the different points on the model of the tree can be obtained using the force model. The validity of the model will be verified by regression on the experimental and model acceleration values at the same locations on the tree.

One of the important parameters in efficiency of the canopy shakers is the amount of canopy penetration by the tines. Since the tree size varies even within the rows, the tines have to be moved as the driver moves along the row. The existing canopy shakers designed by OXBO® have in place a tree follower routine that moves the tines in and out of the tree canopy automatically. But this system monitors the pressure exerted by the tines to control the movement of the tines. The current system is not working very well and in most cases is disabled by the operator. We have developed a new
approach for this problem. This new approach uses the distance of the tines from the canopy edge to move the tines. To determine the distance from the canopy to the tines, different hardware options were investigated. The infra-red range point distance sensors were used to study the feasibility of their use but the performance was not as expected in the outdoor conditions though they performed very well indoor. Right now the sensors that are being planned to be used are Hokuyo®, SICK® and ultrasonic range finders. The communication algorithm and hardware are developed. We are waiting for the end of the harvesting season to install and test this new system on the harvesting machines. The validation of the analytical model for the tree is also being done and is expected to be completed by mid-June 2009.

**Areas where progress exceeded expectations:**
All the proposed objectives were accomplished or currently being carried out.

**Areas where progress didn’t meet expectations:**
None

**Impact of accomplishments towards overall goals of funding:**
The analytical model will help in determining the optimum machine parameters for different variety and size of citrus trees. This will be possible without actual experiments given all the required measurements are available for a typical tree of a given variety and size. These parameters can then be used to adjust the canopy shaker during harvest to achieve variable rate harvesting.

**Presentations associated with 2008-09 efforts:**

**Publications from 2008-09 efforts:**
Refereed:

Non-refereed:

**Next steps:**

**Analytical model validation:**
Validate the analytical model for predicting the force distribution in the tree canopy for different machine parameters and tree types.

**Prototype of control system:**
Develop a prototype of the tine control system explained earlier. Test this prototype of the automated tine control system in laboratory conditions. Conduct tests using the above mentioned prototype in the field using an actual canopy shaker.
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Mechanical Harvesting and Abscission

Investigator:
Ehsani, R. Citrus Research and Education Center, University of Florida

Objective(s) Pursued (Priority Topics):
Develop engineering solutions to reduce trash in mechanically harvested loads of fruit

Specific Objectives:
Trash detection and removal system for a canopy shake and catch harvester using machine vision and additional spinners

a. To design an efficient trash removal system by adding additional spinners on the harvester.
b. To build the efficient trash removal system designed in objective described above.
c. To test the trash removal system on the harvester during actual harvesting and to quantify the performance of the design using the computer vision system developed previously.
d. To fine-tune the trash removal design and write a final report.

Detailed Accomplishments in 2008-09:
In the 2008-09 period, two design concepts were proposed along with machine vision based approach, to quantify and efficiently remove trash materials during mechanical harvesting. The first proposed method (Figure 1) is to extend the spinners at the outlet of the conveyer system of the harvester by adding another set of 14 inch-long spinners. Based on the observation of the current harvesters being used, these spinners do not seem to be working properly, as they are not aligned and gaps are observed between spinners. The design of this system was completed and is currently being built at the machine shop in the Agricultural and Biological Engineering Department.

Figure 1. Sketch for adding additional set of spinners at the outlet of the conveyer system of the harvester.

Figure 2. Sketch showing installation of sets of spinners on a catch pan to remove trash more efficiently.
Second approach to remove trash material is sketched in Figure 2. For this proposed method, a set of spinners are added on the catch pan parallel to the fruit travel direction, so that leaves and branched are removed while fruit are being moved on the catch pan. The method needs a lot more and longer spinners to cover the catch pan and requires a major modification of the harvester. Thus a replication of only one section of the catch pan is designed and currently being built at the machine shop. For these methods, more spinners, gears, bearings, hydraulic motors and other necessary materials were purchased. We expect to complete building the hardware systems by mid May.

Figure 3 shows a geo-referenced map of leaf weight, which was estimated from images taken at the time of harvesting. It is clear that the leaf weight varies depending on the location, indicating some factors may exist affecting the spatial variability of leaf weight. Figure 4 shows the relationship between actual and estimated by the machine vision system for fruit and leaf weight. The system was able to estimate the fruit weight very accurately with an $R^2$ of 0.983, however needs more improvement for leaf weight estimation.

Currently the two proposed systems are being built. As soon as they are completed, we will start experiments to evaluate the performance of these designs. Fruit and trash samples will be obtained from the Lykes grove during mechanical harvesting and brought to the Agricultural and Biological Engineering Department. The system will be tested.
with and without the medications and the results will be compared to identify the efficiency of the modifications. While conducting the experiments, the trash removal design will be fine-tuned and a final report will be written once the experiments are finished.

**Areas where progress exceeded expectations:**
All the proposed objectives were accomplished or currently being carried out.

**Areas where progress didn’t meet expectations:**
The testing and fine-tuning of the proposed trash removal systems are still being carried out, and it is expected that testing of the modified systems will be completed by the end of June 2009.

**Impact of accomplishments towards overall goals of funding:**
This additional set of spinners will remove trash more efficiently since the harvested fruit and trash materials will have more contact with spinners and pass through without clogging the system.

**Presentations associated with 2008-09 efforts:**

**Publications from 2008-09 efforts:**
Refereed:

Non-refereed:
Next steps:
Field tests for the proposed modifications:
The proposed two modifications for more efficient trash removal need to be tested during actual harvesting. It might be difficult to quantify the effect of the modifications since the harvester is continuously used during the harvesting season and there may not be enough time for retrofitting the harvester and conducting field experiments. We will make every effort to accomplish field testing during 2009-2010 harvesting season. Along with the continuation of the machine vision based trash detection system and utilization of extended rollers for more trash removal, we propose also the following methods to remove trash material efficiently.

High Pressure Blowers:
We propose to attach high pressure blowers on the conveyor system where there is an opening before the spinners to blow leaves and twigs. This can reduce the amount of leaves and twigs entering the truck. The high pressurized air from the blower will force the leaves and twigs to pass through the gap existing before the spinners. Since the leaves and twigs are light in weight, the blowers can be installed slightly tilted towards the catch frame so that the leaves and twigs are blown away in the opposite direction of the truck to avoid mixing of trash with the harvested fruit.

Modification of Catch Frame:
We propose to change the base of the catch frame to be composed of metal bars so that leaves and twigs could fall through between the bars while being moved to the brushes. The spacing between the metal bars should be adequate enough so that citrus fruit should not fall down but other smaller leaves and twigs could fall through it. Since there is a rolling mechanism underneath the catch frame, it is difficult for the trash to fall to the ground. An additional plate below the catch frame is needed and made to be moved simultaneously with the catch frame so that at the end of the catch frame the trash is automatically disposed from the plate. This modification can greatly reduce the amount of initial trash and the remaining trash is taken care of by the brushes and rollers.

Modification to tines (material and configuration):
The shaking and moving metal tines create enough force to break tree branches, twigs and leaves, which fall onto the citrus catch frame. The tines need to be constructed of a more flexible material or allow distributed flex joint areas, which creates less force on the tree, thus reduces breakage. The objective is the tine contours with the various branches, versus breaking anything in its path. Also, to meet this objective, an independent tine clamping unit needs to be incorporated into the cantilever assembly, which allows better opportunity for the machine maintenance mechanic to properly torque the tine clamps. This will make sure the tine force is adequately distributed from the start. Force sensors can be incorporated into the tines, thus alerting the machine operator of excessive travel speed. Incorporating a new tine methodology into a Variable Rate Shaking System that
recognizes various tree sizes, thus providing the appropriate shaking force will help reduce trash.

**Modification to the conveyor:**
Instead of the citrus traveling along the Long Conveyor as a means to get to the Elevator, instead use this zone for intermittent tumbling and de-stemming purposes. A revised pinch roller system needs to be developed which uniformly positions and moves the citrus at an adequate flow rate that properly rids it of any leaves and stems.

**Independent trash removal unit:**
We also propose to develop an independent unit which will be used to remove trash material from mechanically harvested fruit. This unit should be fast enough to keep up with the harvested loads and be able to completely remove smaller twigs and leaves.