IFAS Citrus Initiative
Annual Research and Extension Progress Report 2012-13

Title: Machine Enhancement for Citrus Mechanical Harvesting Equipment
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Objective(s) Pursued:

Objective 1: Machine improvement and alternative design to reduce tree structural damage

A- Improving the design of fruit removal tines
- Determining mechanical and physical properties of citrus wood
- Statistical modeling of tree limbs
- Formulation of mechanistic tree damage and fruit detachment model
- Perform optimization based on numerical techniques

B- Developing alternative fruit removal systems

Objective 2: Improved automated tine control system

Objective 3: Enhancing the application efficiency of an abscission compound using a smart sprayer
- To test the potential of the variable rate axial-fan airblast sprayer retrofit for increasing the abscission-inducing chemical application efficiency in different size citrus canopies
- Evaluating the targeted delivery, coverage, droplet deposition density, and uniformity of chemical applications

Detailed Accomplishments in FY2012-13:

Objective 1-A: Improving the design of fruit removal tines:
- *Mechanical and physical properties of citrus wood:* The mechanical and physical properties of fresh citrus wood were determined. The average values of the mechanical properties such as flexural modulus, modulus of rupture, stress at proportional limit, work to maximum load in bending, and physical properties such as specific gravity, moisture content, and damping ratio were used to define the parameters of a numerical model of tree limbs.
- *Statistical modeling of limbs:* The tree was classified into three zones: top, middle, and bottom. The tines corresponding to each zone were designed based on the probability of the tines hitting a main structural branch or small branches with fruit. These probabilities were different in each zone. A methodology was developed to model sets of tree limb prototypes having similar spatial distribution and vibrational characteristics. This methodology was used to model the limb as a truncated conical elastic beam with secondary branches and fruit masses added onto the main limb at their point of attachment.
- *Formulation of mechanistic tree damage and fruit detachment model:* The physical phenomenon of tree injury and fruit removal was quantified in terms of mathematical quantity such as stress and acceleration using mechanistic models. A tree damage and fruit detachment model was formulated based on the results from the numerical methods. A finite element method was used to find the transient response of the tree limbs considering mass proportional damping. The transient response of the tree limbs under impact from sinusoidal vibrating tines (shaking member) of the harvesting machine was used to calculate mechanistic fruit detachment and the tree damage index. These mechanistic models were used in optimization formulations to predict the optimum tine design and the operating parameters of the shaker for each zone.

- *Optimization based on numerical models:* A two-part optimization strategy was used. The first part optimized the shaker based on structural variables such as stiffness and lengths of the metal and plastic segments of the tines. The second part optimized the shaking parameters such as frequency and amplitude of the tines.

The results from objective 1-A are summarized below:

- Mechanical properties of fresh citrus wood were determined: elastic modulus (8.5 GPa), the modulus of rupture (67.3 MPa), specific gravity (1.4508 g/cc), and damping ratio (10.78%). Samples were taken from primary branches with diameter greater than 3 inches.
- An analytical model was developed which describes the physical characteristics of tree limbs in three different zones of the tree canopy, top, middle, bottom.
- A methodology was developed which used finite element analysis to optimize the current fruit removal system.
- A combination of low (nylon) and high stiffness (steel tube) tines in the ratio of approximately 3:1 works best for primary limbs that curve down sharply, which are typically located in the bottom and middle zones. For the top zone, which consists of limbs that are long and point upwards, low stiffness tines worked best.
- High frequency and low amplitude vibrations showed good results for most of the proposed two-piece designs.
- Structural optimization of the canopy shaker resulted in a 15-20% reduction in tree damage simulations.

Objective 1-B: Development of an alternative fruit removal system

A four-stage harvesting management technique to increase harvesting efficiency was established. The four stages are: ground preparation, mechanical harvesting, fruit sweeping, and fruit pick-up. A material-sweeping unit and a modified pick-up head for the Oxbo 3200 were developed, and a utility vehicle (Bobcat Toolcat 5610) with a surface conditioning attachment (flail cutter) was obtained. Preliminary tests involved: i. Ground preparation to condition the fruit drop area. ii. Machine harvesting by the Oxbo 3210. iii. Fruit sweeping from underneath the tree canopy toward the center aisle. iv. Fruit pick-up by the Oxbo 3200. The main focus was put on modifying the Oxbo 3200 to create a more simplistic and efficient fruit pick-up machine system (Fig. 1). The machine was evaluated at the CREC facility, Lykes Brighton orchard, and Lykes Lake Placid orchard.

The most challenging feat for the modified pick-up machine was adapting to the worst-case scenarios in an orchard: very loose sand or swale areas. Also, 38 soil compaction tests were performed. The measurement differences taken from underneath the canopy varied as much as 105 percent compared with measurements taken from the vehicle wheel paths. On average, the difference between underneath the canopy and the center of the row aisle was 47 percent. This data proves useful when determining mechanical system spring tension and hydraulic motor torque requirements. The present development period improvements include:

- Automating the hydraulic cylinders, thus eliminating the need for the operator to predict ground clearance heights and gap areas while traveling. Mechanical devices, such as wheels and nylon arrows, have been incorporated to actuate limit switches. Soft sand has been problematic for predicting system mechanism heights.
- After testing sandy soil, it was determined that the floating mechanism needed to be modified. Several modifications were developed and tested, including both resistant and non-resistant methodologies, which included: lower mounted and longer floating rods,

rubber folds, a combination nylon brush and flap wheel, counteracting flap wheels and independent spring plungers. The later mechanisms have been the most successful.
- New conveyor belt risers were developed and incorporated in order to hold the fruit while increasing both 55 and 35 degree inclination angles.

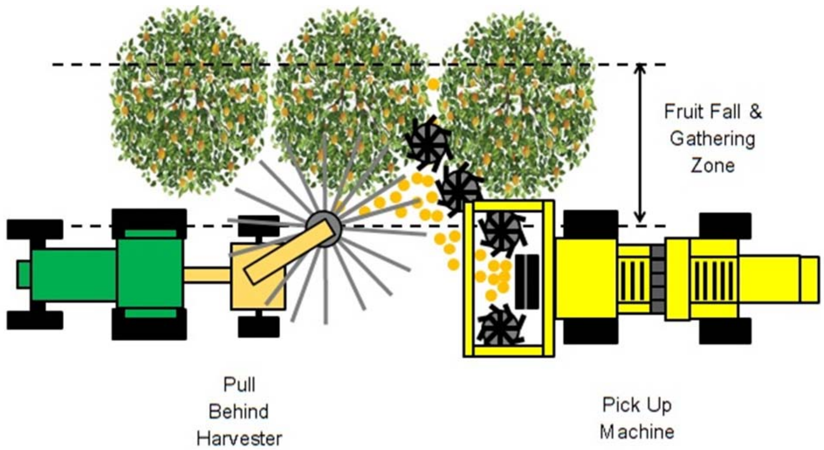

Fig. 1. Concept drawing of a simplistic fruit ground drop and pick up harvesting system.

The modified pick-up head for the Oxbo 3200 consisted of two subsystems; a fruit sweeper system and a fruit pick-up system. For the fruit pick-up subsystem, a combination of a center flap wheel and push rod float bars were used. Four different versions of the fruit sweeper were developed (Fig. 2) as described below:

1) Two flap wheel wings with a utility vehicle material-sweeping unit for underneath the canopy.
    - It was determined that the utility vehicle was not necessary
2) Two centipede wings with one centipede underneath the canopy.
    - Soil conditions posed a challenge, which stopped the machine from moving.
    - Soil surface depth variances required a device that can adapt more easily.
    - The hydraulic system was divided into two valves.
3) Two modified centipede wings with two wheel-sweeps for underneath the canopy.
    - The wheel-sweeps outperformed the modified centipede.
    - The hydraulic system bogged down, mostly with the center flap wheel and wings.
4) Two wheel-sweeps and two additional wheel-sweeps for underneath the canopy.
    - Hydraulic motor torques were increased by 185 N-m for the wheel-sweeps underneath the canopy, 126 N-m for the two wing wheel-sweep, and 45 N-m for the center flap wheel.
    - Due to lack of hydraulic flow rate and motor torque as well as gaps in the sweeping system, a low percentage of fruit were swept and picked up.

The pick-up system has evolved and is in the process of overcoming hydraulic supply and motor torque deficiencies, vulnerable system device gap areas, and operator dependency versus automation. The biggest challenge is creating a machine that can function in the worst-case scenarios, i.e. soft sand and swell areas.

Fig. 2. The modified Oxbo 3200: 1. flap-wheel. 2. centipede. 3. combination centipede and wheel-sweep. 4. wheel-sweep.

Objective 2: Improved automated tine control system

The controller board that was developed last year was redesigned to address the issues that were found in the previous design (Fig. 3). The control algorithm used in the new board is the same as the one used last year thus, the response time of the system is still the same. The penetration settings of the tine system were not changed, but several functionalities were added to the new system; for instance, the tine position change can be recorded. Also, all the settings can now be accessed by the operator/driver directly in the control box, as compared to the previous design where the operator needed to run a hyperterminal program to change the settings. The connector board provides a quick connect capability for all the sensors (ultrasonic and asm) and also for the Tine Control Connection from the Oxbo System. Also new is a joystick for controlling the tine manually and the same joystick is also used for changing the configurations of the system. The board also translates the TTL Serial from the main controller to RS232 signal for GPS. The LCD connector on this board uses the same pin configuration as found on the main controller. The new system is now enclosed. The ultrasonic sensors are now protected with aluminum enclosures.

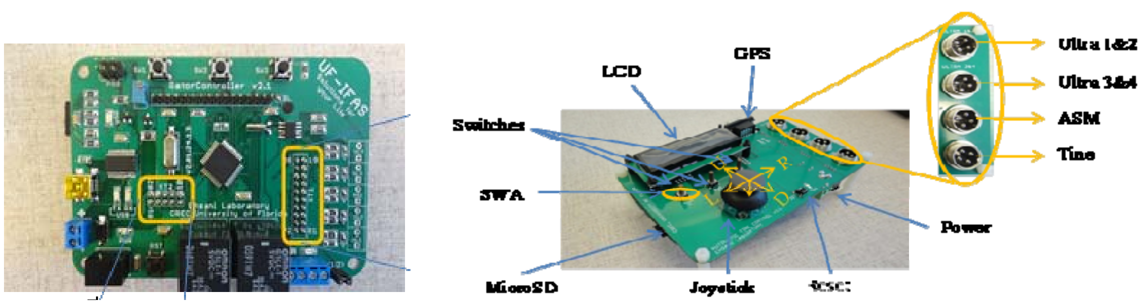

Fig. 3. New connector board designed for automated tine control.

Objective 3: Enhancing the application efficiency of an abscission compound using smart sprayer

This study evaluated an air-assisted sprayer retrofit, i.e. smart sprayer, that was developed through a USDA-SCRI grant, and two other sprayers commonly used in citrus production for their application efficiency in spraying the abscission chemical (simulated using water as spray with tracer dye as spray mix). Three sprayers: a) an air-assisted sprayer retrofit, b) a conventional airblast sprayer and b) a multifan vertical airblast sprayer (Oxbo) were tested in this study. A series of field tests were conducted to measure spray deposition and coverage for each sprayer.

Data analysis results revealed that:

- For all three sprayers, deposition and coverage on the canopy surface was higher than at 0.6 m inside the canopies.
- The smart sprayer resulted in the same amount of spray deposition as the other two sprayers, while using 30% less spray volume for medium canopies and 70% less spray volume for small canopies. The WSP results confirmed the above trends.
- Multifan vertical airblast sprayer treatments resulted in relatively less deposition and coverage at lower sections of small (both canopy surface and 0.6 m inside) and 0.6 m inside of large canopies. Thus, the above sprayer is more suited for applications in commercial orchards with medium sized, less dense, and hedged canopies; whereas the air-assisted sprayer retrofit may be well suited for all types of canopies as it adjusts air-assist and liquid rates based on canopy size.

Areas where progress exceeded expectations:

Objective 1-A: The results for the properties of fresh citrus wood can also be used for other research involving fresh citrus wood.

Objective 1-B: All proposed objectives were met.

Objective 2: The addition of new capabilities such GPS logging and a new interactive display were beyond the proposed scope of work for this year.

Objective 3: All proposed quarterly objectives were accomplished. In addition to using WSPs, the study also used a reliable fluorometry technique which was beyond the proposed scope of work for this year to confirm results.

Areas where progress did not meet expectations:

Objective 1-A: Did not have time to validate the numerical model.

Objective 1-B: Most tests were performed at the CREC with little or no fruit loads. We found that running the machine under field conditions was more challenging than at the CREC grove.

Objective 2: The new control board was not ready for installation and testing on the Oxbo 3220.

Objective 3: All objectives were met.

Impact of accomplishments towards overall goals of funding:

Objective 1-A: Until now, the design and development of citrus canopy shakers has been mainly based on trial and error. This study developed a modeling approach to simulate the tree canopy and canopy shaker interaction and proposed an optimization approach that maximizes fruit removal while reducing tree structural damage. The result proposed an adaptive shaking system which is an advancement over the existing uniform shaking system. This methodology can also be applied to optimize harvesting systems for other fruits. The results of the simulation study suggest the need for design changes which can be incorporated into either the exiting machine or a new machine.

Objective 1-B: Developing an efficient fruit pick-up system can increase the efficiency of harvesting of citrus fruit, which reduces harvesting costs. In particular, it can help in cases of excessive fruit drop.

Objective 2: An automated tine control system can increase the efficiency of the operator by reducing the number of tasks required to operate the harvester during driving. Correct positioning of the tine system in the canopy can potentially increase fruit removal while reducing tree damage.

Objective 3: The effectiveness of the abscission compound is heavily dependent on the uniformity and accurate deposition during spraying throughout the canopy. The results of this study show that smart sprayer was a better choice for application of the abscission compound.

Presentations associated with 2012-13 efforts:

Khot, L. R., R. Ehsani, J. M. Maja, J. Campoy, and C. Wellington. 2013. An enhanced variable rate axial-fan airblast sprayer for citrus. Poster no. 27, Posters and Pastries Research Gallery, March 1st, 2013, Organized by Citrus Research and Education Center, Lake Alfred, FL.

Publications from 2012-13 efforts:

Refereed:

1. Yamakawa, M., L. R. Khot, R. Ehsani, N. Kondo. 2012. Real-time nondestructive citrus fruit quality monitoring system: development and laboratory testing. Agricultural Engineering International: CIGR Journal, 14(3):117-124.
2. Shamshiri, R., R. Ehsani, J.M. Maja, and F. Roka. 2013. Determining machine efficiency parameters for a citrus canopy shaker using yield monitor data. Applied Engineering in Agriculture. 29(1): 33-41.
3. Jadhav, U., L. R. Khot, R. Ehsani, J. K. Schueller. 2013. Volumetric mass flow sensor for citrus mechanical harvesting machines. 17 pages. Journal of Computers and Electronics. (submitted)
4. Khot, L. R., R. Ehsani, J. M. Maja, J. Campoy, and C. Wellington. 2013. Evaluation of an air-assisted sprayer retrofit and two airblast sprayers deposition and coverage in citrus orchards. (Under internal review)
5. Gupta, S.K., R. Ehsani, N.H. Kim, 2013.Statistical modeling of limb prototypes using response surface methodology. (in progress)
6. Gupta, S.K., R. Ehsani, N.H. Kim. 2013. Optimizing citrus harvesting system based mechanistic tree damage and fruit detachment models. (in progress)

Non- Refereed

1. Khot, L.R., R. Ehsani, G. Albrigo, W. Swen, J. C. Neto, J. Campoy and C. Wellington. 2012. Validation of variable rate spray decision rules in intricate micro-metrological conditions. Paper No. 1314. 11th International Conference on Precision Agriculture (ICPA), July 15-18, 2012, Indianapolis, IN, USA.
2. Gupta, S. K. 2013. Optimization of citrus harvesting system based on mechanistic tree damage and fruit detachment models. MS thesis. University of Florida.

Next steps:

Objective 1-A: Based on the simulation study, a modified fruit removal system needs to be built to validate the simulation results by field tests.

Objective 1-B: The latest design of the fruit pick-up head has showed promise; however, there are several issues that need to be addressed. The next step is to address all the existing issues and conduct more field trials.

Objective 2: The automated tine control system can be a part of the future mechanical harvesting design where controlling the distance between the shaking head and tree canopy is important. It can also be used in other applications for other tree crops such as blossom thinning systems used in apples and peaches.

Objective 3: Since the registration of abscission compound is not clear at this point, no further work is proposed.