Washington Tree Fruit Research Commission
FallTechnology Research Review
October 28, 2010
CPAAS, Prosser

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FINAL PROJECT REPORT

Project Title: Robotic scout for tree fruit

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Cooperators: None

Other funding sources

Agency Name: USDA, SCRI Funding
Amount requested/awarded: $200,000
Notes: This is matching funding per the CASC SCRI project

Total Project Funding:

Budget History:

Item	2010
Salaries	$111,707
Benefits	$44,056
Wages	
Benefits	
Equipment	
Supplies	
Travel	$11,000
Miscellaneous	
Scout Prototype	$8,237
Subcontract to CMU (field expenses for integration)	$25,000
Total	$200,000

Footnotes: In addition to the above budget, in 2010 project included $2875 in WTFRC Collaborative expenses.

OBJECTIVES

Vision Robotics Corporation (VRC) has been working closely with the Washington Tree Fruit Research Commission (WTFRC, or the Commission) to develop a robotic harvester for tree fruit. The first step is the development of a Scout that scans the trees with cameras, and locates, counts and sizes the fruit. The second step is the development of a Harvester that uses the location information from the Scout to cost-effectively pick the fruit. This project is part of the "Comprehensive Automation for Specialty Crops" (CASC) SCRI project.

The goals for 2010 were to improve the apple detection and sizing accuracy for both red and green fruit, and to upgrade the prototype Scout's robustness and operating scale. The project was to culminate with field tests to demonstrate crop load estimation on a significantly larger scale than in previous years. The specific objectives included:

- Crop Load Estimates
  - Obtain 90%+ yield accuracy for less densely packed orchards;
  - Obtain 85%+ yield accuracy for highly clustered trees;
  - Benchmark 2009 sizing performance.
- Prototype Upgrades
  - Operate in temperatures in excess of 100°F;
  - Incorporate industrial flashes;
  - Upgrade mast to be lighter, more robust and easier to handle.
- Increase operational speed to between 1 and 2 mph.
- GPS-reference scans and feed data into the Carnegie Mellon University (CMU) GIS database.
- Increase analysis speed to where data from a 100' scan of less densely packed fruit can be completed within 30 minutes.
- Integrate with the CMU Autonomous Prime Mover (APM).

VRC originally proposed a test plan to scout different varieties, growing configurations and stages of growth. Specifically, the field tests were to consist of three separate trips to Washington orchards to scout six different 1 acre sub-blocks, one of which was to be scanned during all three trips. The three trips were to permit testing at three different growing stages: one week before harvest, four weeks before harvest and when the apples are approximately one inch in diameter. Based on input from the Commission, the test plan was modified to scouting two blocks where each was at least five acres in size. These tests would result in significantly more data collected than originally planned. As such, both sets of field tests were conducted during the same trip to Washington.

In addition, the Scout system was designed to work with fruiting walls approximately 18"-24" thick. One of the blocks scanned during the field tests had trees in excess of 36"-48" thick. (This block was selected for the strength of the red coloring of its apples at the time of scanning.) Apples on the far side of the tree were not visible to the Scout cameras, so a statistical analysis is required in order to estimate the crop load.

VRC originally requested $275,000 dollars for the project and $200,000 was awarded. The decrease in budget was partially offset by decreasing the number of field tests and trips to Washington. In addition, less effort was available to refine detection and sizing algorithms, and to work with smaller apples.

SIGNIFICANT FINDINGS

Field Test Results

McDougal Farms, Ambrosia Block (Green Fruit)



- The crop load estimate for 6 acres was 560,358 which was
- 75% of the load extrapolated from hand count of 240' to estimate of 742,388.
- Raw count was 299,997.
- Counts from four trials each of two 60' hand count sections each self-consistent within 5%.
- Median apple diameter estimate was 2.60” which was within 1% of the median of 2.58” of the 240' of hand measured apples.
- Raw median apple diameter was 2.62”.

Washington Fruit and Produce, Gala Block (Red Fruit)



- The crop load estimate for 11 acres (every other row was scanned and the results were doubled) was 1,445,143 which was
- 94% of the load extrapolated from hand count of 240' to estimate of 1,532,232.
- Raw count was 284,477 for 1/2 of the block (5.5 acres).
- Counts from four trials each of four 60' hand count sections each self-consistent within 8.5%.
- Median apple diameter estimate was 2.56” which was within 3% of the median of 2.63” of the 240' of hand measured apples.
- Raw median apple diameter was 2.49”.

Crop Distribution

- The Scout scanned 11.5 acres over two blocks, which is a significant amount data collected about the orchards. While two blocks do not represent a large statistical data set, it does demonstrate the potential for the Scout to enable precision farming.
  - The 6 acres of ambrosia apples consisted of 30 rows and approximately 5 miles of trees. When broken into approximately 16' sections, the count/section values had
    - median 340,
    - standard deviation 158.7.
  - The 5.5 acres of gala apples consisted of 26 rows and approximately 4.5 miles of trees. When broken into approximately 16' sections, the count/section values had
    - median 513,
    - standard deviation 128.4.

2009 Sizing Benchmark

As noted above, the 2010 sizing performance was extremely accurate, within 3% for the median apple size in the ground truth sections for both blocks scanned. This strong performance was predicated on benchmarking the 2009 results; analyzing actual sizing performance; improving sizing algorithms; and realizing benefits resulting from enhancements elsewhere in the Scout system.

Vision Robotics benchmarked the 2009 software's sizing performance by scanning apples of known sizes in several different configurations.

The raw average apple diameter was 2.2” while the true average diameter was 2.9”.

The data have been used to create a statistical model that can be applied to correct for such system biases.

Speed and Robustness

- Using standard off the shelf computers, industrial flashes, forced air cooling, etc. the Scout worked continuously in temperatures well in excess of 100°F during the field tests.
- Ground speeds in excess of 1 mph were achieved using a camera frame rates of 20 images per second and the new flashes.
- The industrial flashes provide sufficient light to enable the Scout to operate in all sun conditions, a flash rate high enough for production, and robustness that approaches that required for production.
- The system has been optimized such that the median time to analyze 100' of data was 30 - 70 minutes, depending on the block from which the data were collected.

RESULTS & DISCUSSION

Moving the Scout system towards production requires strong performance in counting and sizing the apples, high processing speed, high system robustness and an effective means of displaying the data. In 2010, all these components were significantly improved.

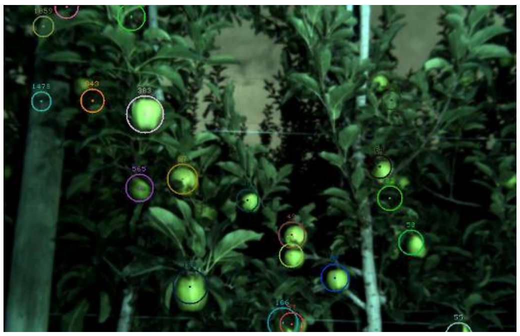
Estimation Performance

Bias Correction

In a crop load estimation system such as the Scout, it is likely that biases will inherently be present. Causes of such biases could include software factors such as a systematic tendency to undersize fruit during analysis, as well as physical factors such as high tree thickness causing some fruit to not be visible in captured images (and thus not counted). While the variability of such biases across different orchards and apple varieties is not yet known, they are likely to remain consistent through a block. Consequently, a small set of hand collected data can be used to develop a statistical model to correct the bias, transforming “raw” data into more accurate “statistically-adjusted” data. For example, by applying bias correction, an estimate is equally accurate regardless of whether the Scout consistently identifies 99% of the apples correctly with zero double counts or false positives, or consistently estimates 80% of the apple count regardless of the number of correct versus incorrect detections. Undoubtedly, the better the system is at correctly distinguishing apples, the more likely it is to have a consistent count.

In 2010, hand counts from 60' sections were used to perform bias correction. The ratios of the median hand measured diameter to the median Scout estimated diameter were 0.98 and 1.06 for the green and red apples, respectively. These near-unity diameter scaling factors demonstrate that only a small bias was present in the median size estimates, and that potentially either an extremely small or no bias correction will be required for sizing

To correct for bias in count estimates, a scaling factor was determined for each of the green and red apple scans by averaging the ratio of the hand count to the Scout count over the four 60' sections. The resulting count scaling factors were 1.87 and 2.54 for the green and red apples, respectively. The relatively large separation of these values from unity shows that, despite being rather self-consistent, a fairly large bias was present in count estimates. A brief review of images in which detected fruit were outlined with circles suggested that a large percentage of more distant fruit were not visible to the Scout's cameras because they either were obscured by closer foliage and fruit, or were insufficiently illuminated by the flashes. In general, as illustrated in the images below, the majority of the fruit detected by the Scout were on the close side of the trunk, which roughly corroborates a scaling factor of 2. One potential approach to combating such a source of bias would be to detect tree trunks, filter detected fruit to include only those on the near side of the trees, and then double the estimated count. An alternative is for the Scout to determine the thickness of the canopy and determine the depth into which is sees a large and uniform number of apples. It could then filter out all apples beyond that depth and use a scaling factor between that depth and the total canopy thickness. Both these logical refinements would lead to a more stable bias factor across different orchards.



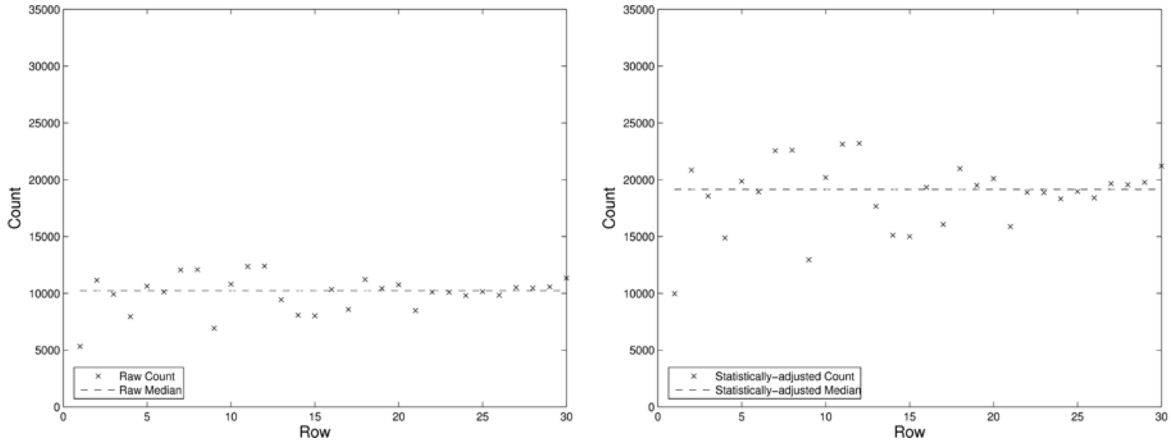
Apple Count

To improve raw estimation performance, the first step in 2010 was to further analyze the Scout's 2009 performance. The estimates of the number of apples in the 100' sections of jazz rows in the Allan Brothers orchard scanned in 2009 were typically accurate (based on 4-6 runs) to within 25% using 2009 software, with some of the runs achieving 98% accuracy. The Scout count includes correctly identified apples, doubly counted apples, missed apples and false detections. The results of these analyses, coupled with experience gained improving algorithm performance in 2009, provided target areas for enhancement in 2010.

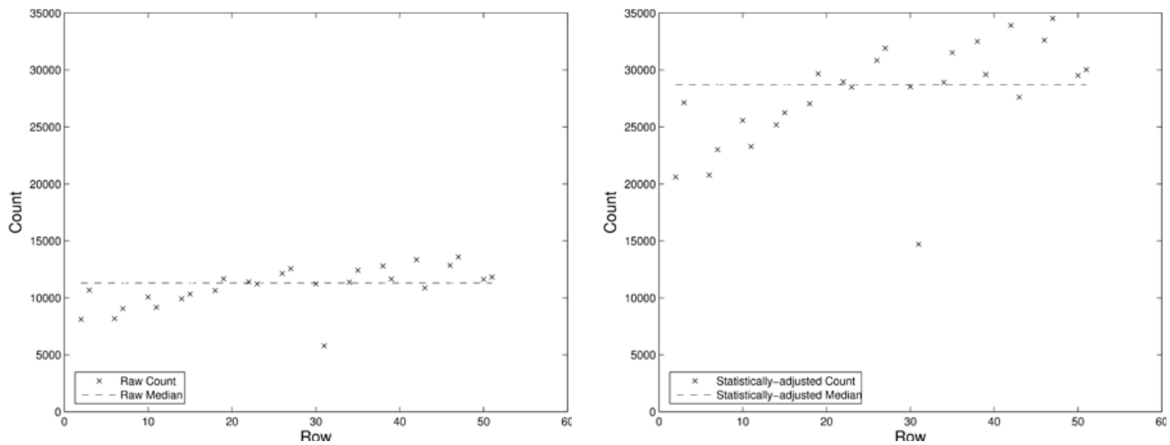
VRC has implemented an improved detection algorithm with better identification of individual apples (particularly those of mixed color) and stronger performance in identifying individual apples within clusters. The new algorithm uses the same software for detecting both red and green apples, but requires different input filters. The visual odometry software module is used to determine how much the cameras have moved between pictures and to determine the relative positions between cameras. The module has been enhanced to better correlate the portions of the images that overlap between cameras, which helps to eliminate double counts due to multiple cameras seeing the same apple (the largest number of errors in 2009) and enables improved location and size determination by incorporating more views of the same apple from different perspectives.

Significant improvements to the collection software and the prototype design also improved detection performance. Using data collected from the 2009 field tests, the team optimized the camera/mast configuration, adding one additional camera pair (nine as opposed to eight in 2009) and changing the relative locations and orientations to better image entire trees. Additionally, camera settings were adjusted and the auto-exposure algorithms were updated. Taken together, these modifications have improved the capability of the Scout to see the apples on the trees, which leads directly to improved estimation accuracy.

The figures below show the raw and statistically-adjusted counts for the 30 rows of green apples, and the 26 rows of red apples. The median and standard deviation of the statistically-adjusted row counts were 17820 and 2799 for the green apples and 28709 and 4548 for the red apples. The plots illustrate that while a significant bias correction factor has been applied, the raw counts are overall fairly consistent from row to row. Note that row 31 of the red apple block was of substantially shorter length than the other red apple rows, giving rise to a correspondingly low count.

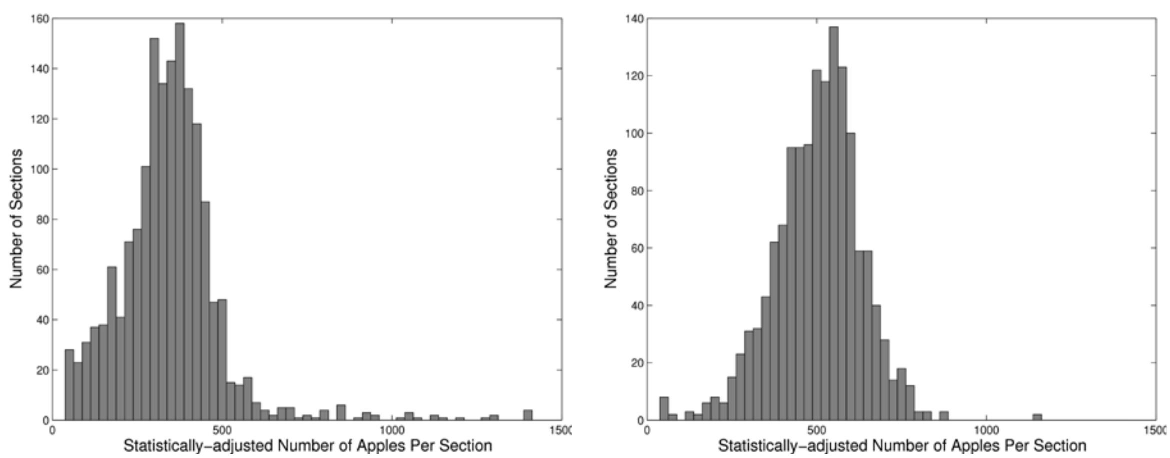


Raw counts (left) and statistically-adjusted counts (right) for 30 scanned green rows



Raw counts (left) and statistically-adjusted counts (right) for 26 scanned red rows

To view the data on a finer scale, each row was divided into approximately 16' sections along the row. Histograms giving the statistically-adjusted counts per section are shown below for the green (left) and red (right) fruit. These plots demonstrate the Scout's ability to detect load variability within the block.



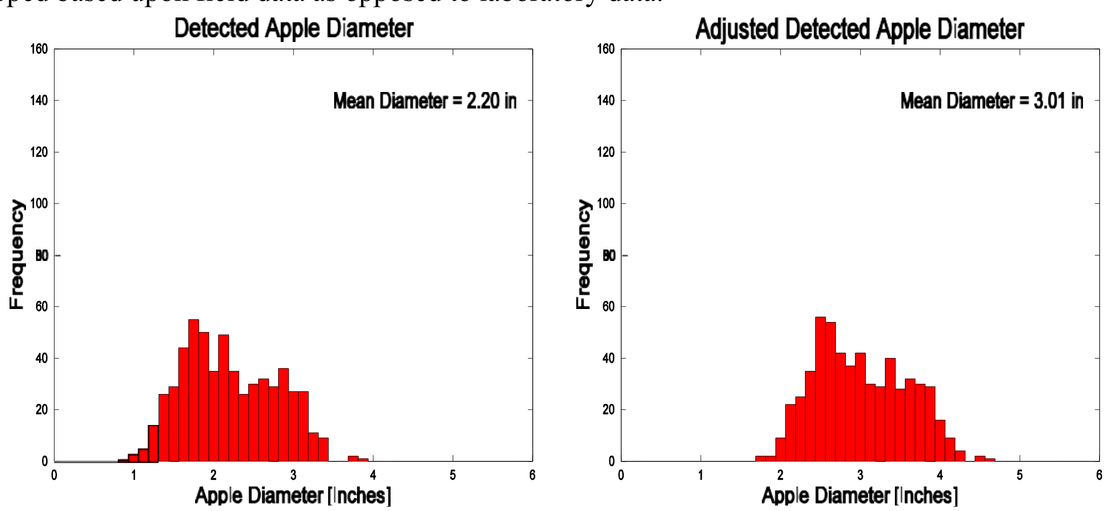
In order to develop a bias correction model and to study the consistency of the Scout's estimates, the hand counted 60' sections were scanned repeatedly and the results are shown in the table below. In all cases, the latter three trials were performed in succession, while the first trial was performed at a different time of day. The counts clearly demonstrate the consistency of the Scout estimates over these trials.

Row	Scout Counts	Consistency
Green 18	829, 780, 772 and 818	7.4%
Green 24	807, 812, 780, and 768	5.7%
Red 10	769, 817, 833 and 819	8.3%
Red19	781, 737, 744 and 726	7.6%
Red 34	777, 851, 844 and 878	12.9%
Red 43	764, 733, 724 and 704	8.5%

Sizing

Analysis of the 2009 sizing performance revealed that partially occluded apples tended to lead to size underestimation with a larger variance than true distributions; the estimates of the range of apple sizes tended to be wider, flatter and shifted to smaller sizes than the actual crop. Sources such as this introduce system biases which can be reduced through the use of statistical modeling. A statistical model was created to adjust the size distribution to addresses these expected inaccuracies. More and improved data from this year's field tests will enable refinement of the model in 2011.

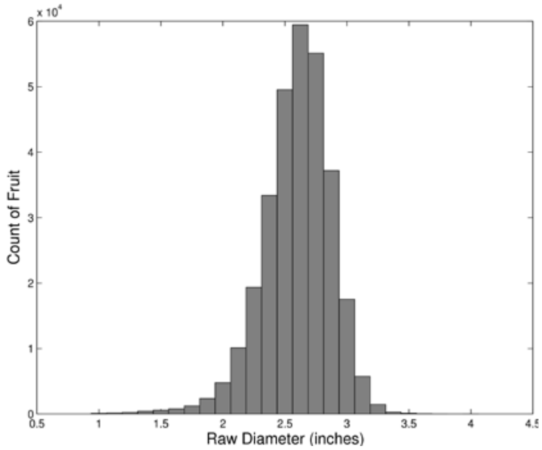
As reported last year, the 2009 raw average size estimates were approximately 20% too small. For the run shown in the below, the raw average apple size was 2.2" diameter, which is 24.1% less than the hand measured average of 2.9" diameter. The histogram of the data after the statistical model was applied shows a mean size of 3.0" diameter, or 3% larger than ground truth. Thus, the statistical modeling is effective in adjusting the mean of the size distribution. The variance of the distribution, however, remains larger than the true variance. This result is, in part, due to the need for a larger sample size when developing the statistical model. Such a larger set will be available when statistical models are developed based upon field data as opposed to laboratory data.



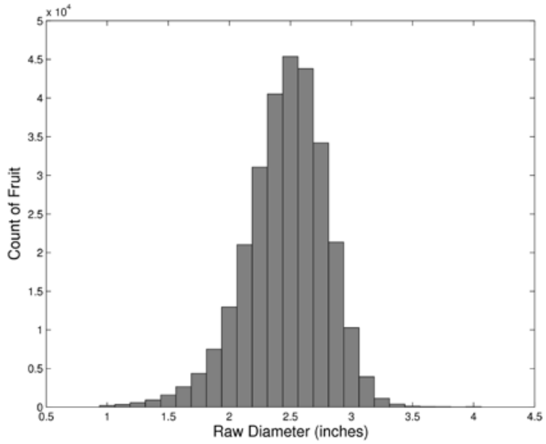
Raw (left) and statistically-adjusted (right) size distribution for a 2009 scan

When compared to 2009, the 2010 Scout produces a better distinction between an individual and the surrounding fruit, leaves and branches in the images. This delineation directly leads to the software more accurately detecting the perimeter of the apples in the images, thereby significantly improving the raw average sizing performance. The 2010 raw and statistically-adjusted (using the simple scaling model) size distributions for the 6 acres of green fruit and the 5.5 acres of red apples are shown below, as are the aggregate hand measured size distributions of fruit in the four 60' sections for green and red apples. Visually comparing the histograms for the raw and hand measured fruit diameters immediately illustrates that very little bias is present in the median size; however, the Scout estimates display a larger variance, as is expected. After bias correction with a near-unity scaling factor, the median green apple diameter was 2.60”, which was 0.78% larger than the hand measured median diameter of 2.58”.

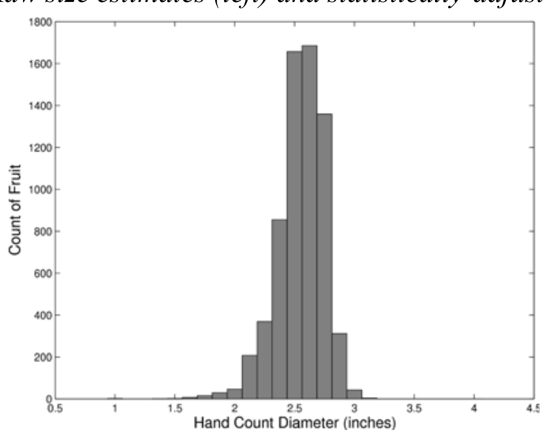
Similarly, the bias-corrected median red apple diameter was 2.56", which was 2.66% smaller than the hand measured median diameter of 2.63".



Raw size estimates (left) and statistically-adjusted size estimates (right) for 30 scanned green rows



Raw size estimates (left) and statistically-adjusted size estimates (right) for 26 scanned red rows



Hand measured apple sizes for 240' of green (left) and red (right) apple

System Robustness

The 2010 Scout prototype and camera module, shown below, represent significant upgrades towards a production design, but the resources necessary to fully weatherize them were not expended. For example, each camera pair is now in a closed module that is straightforward to fully seal, but the time and expense were not taken to use IP65 connectors and gaskets. Similarly, the computers are more robust than those used in 2009, but they are still standard desktop models. Fully weatherized and robust computers are available, but only represent a marginal robustness improvement that, as expected, was not required this year. Active cooling of the electronics cabinet through a fan system was included in the 2010 prototype. VRC conducted several local field tests to debug the prototype and the final unit operated virtually flawlessly during the week of field tests in Washington where the temperatures were in excess of 95°F every day and above 100°F a couple of days.

Scout prototype (left) and camera module (right)

As noted, the improved robustness was a part of the requirement to ensure that the Scout can operate at a production scale. Additional improvements introduced to achieve this goal include:

- Increased Scout scanning speed to 1 mph;
    - Increased camera frame rate;
    - Decreased image density (pictures per inch).
- Incorporated GPS system to geo-reference data.
- Decreased number and increased robustness of electrical connections.
- Debugged software to eliminate crashes.
- Incorporated industrial flashes.

Analysis Speed

The current Scout is approximately 20 times faster than in 2009 when analyzing data from 2009, meeting the goal of analyzing 100' of data within 30 minutes. The speed gains were achieved primarily through parallelization and decreased analysis time because of the new detection algorithms. Analysis times for 2010 data are somewhat longer, with median times of 70 and 59 minutes for 100' of green and red apples, respectively. This increase can be attributed primarily to the blocks, which have significantly more fruit than those scanned in 2009, and to the fact that the scans were significantly longer (the longer runs require the software to track more fruit during each run).

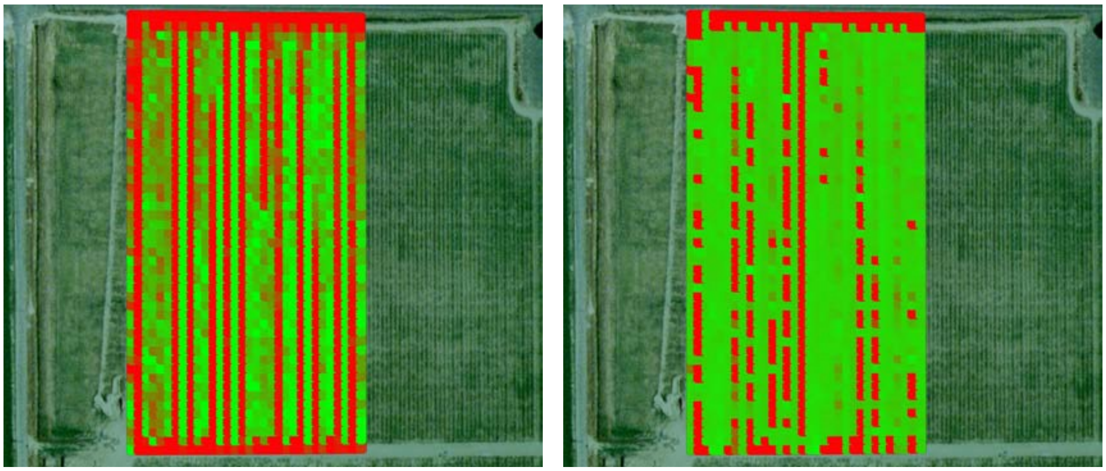
Integration with the APM and CASC GIS System

In 2010, the APM towed the Scout throughout the field tests at the Washington Fruit and Produce orchard. VRC and the CMU team spent almost a full day integrating the two systems, primarily updating the APM software to correctly turn between the rows when towing the Scout. The two robots completed the red apple scans over the course of the next day and a half.

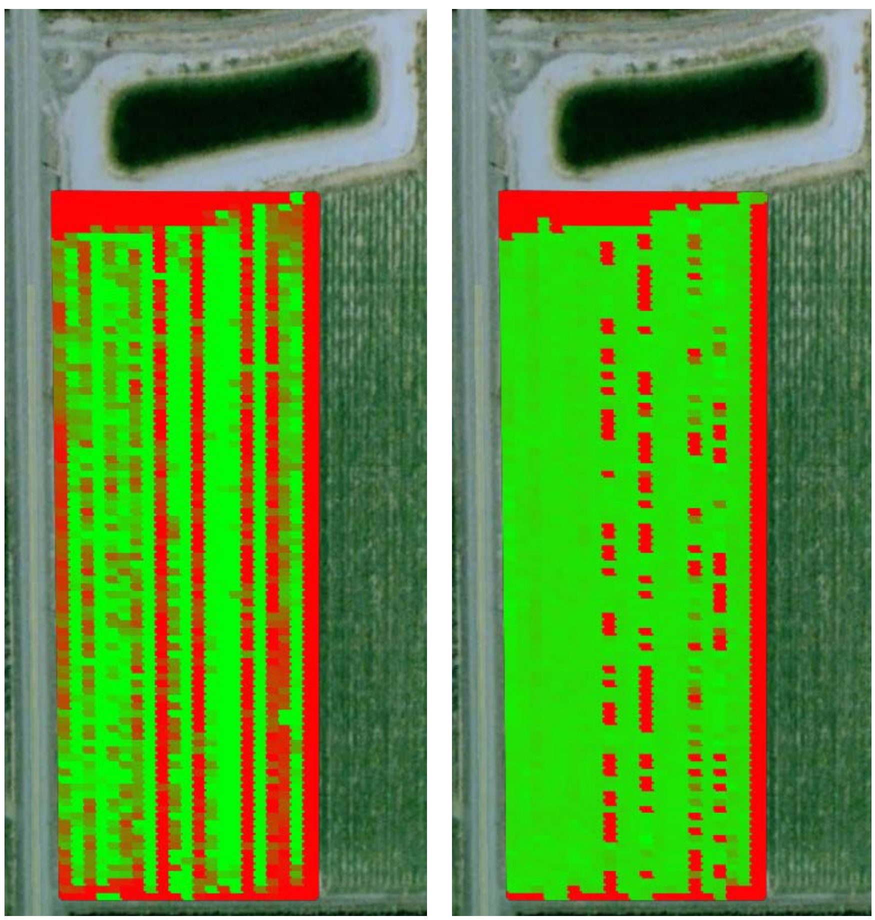
VRC will provide the crop load estimate data to CMU shortly for integration into the GIS database. The data transfer is expected to occur without incident and results are expected soon.

Data Visualization

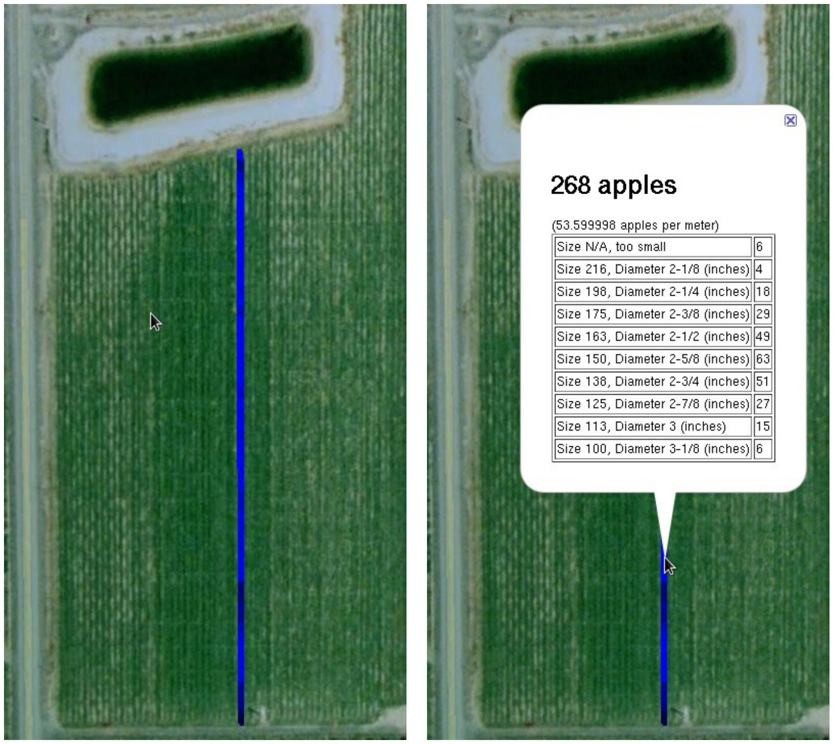
VRC has created a framework for viewing data output by the Scout to provide detail and a debugging environment at VRC. The crop load data can be overlayed onto a Google Earth map of the block to show the crop load and sizes for various resolutions. The yield and median size maps for the red apple data broken down into approximately 16 foot sections along each row are shown below, as are the corresponding maps for the green apple data. In each case, red indicates lower counts (smaller sizes), yellow indicates medium counts (sizes) and green indicates higher counts (larger sizes). Note that some variability is present due to inaccuracies in raw received GPS data. Such inaccuracies likely account for instances where data which should truly appear in rows which are quite red being shifted to appear in neighboring rows (making them very green). Data for a single row can be shown at any resolution, approximately 16' sections here, with darker indicating higher counts. The size histogram for any section can be displayed by clicking on a section of interest, as also shown below.



Yield map (left) and median size map (right) for the 26 scanned red rows



Yield map (left) and median size map (right) for the 30 scanned green rows



Yield map for a single row (left) and size information for a 16' section (right) for a green apple scan

Field Tests

The team wishes to acknowledge and thank everyone that helped make our field tests a success. This includes the McDougals and Washington Fruit and Produce who let us into their orchards as well as helped keep us dry during those hot days. Similarly the CMU and WTFRC teams went way above and beyond reasonable effort. Collectively, we worked from before dawn to late into the night, and even through thunderstorms. Finally, we appreciate and thank the Commission for collecting the ground truth data, both the estimates for the full blocks and the hand counts of small sections within the blocks. During the tests, the Scout collected approximately 9 terabytes of data for analysis. Despite the temperature, rain and sprinkling, it operated all three days and collected data without a failure except for a couple of hard disk related crashes with one of the 12 disks used.

The Future

VRC is pleased with the 2010 progress; the detection software performance (particularly with respect to sizing) and speed was improved, and the Scout demonstrated its ability to scan large blocks with high consistency within a block. The goals for the future include a plan for continued refinement of the apple detection and sizing performance, and further increasing the processing speed with the ultimate goal of achieving real time. One specific goal for 2011 is to analyze the data collected this year to determine a statistical scanning plan to create accurate crop load estimates while scanning only portions of the orchards. An additional key goal is to collect data from a larger and more diverse set of blocks (in terms of varieties and tree configurations) to analyze the variability in the statistical models used for bias correction.

EXECUTIVE SUMMARY

The Scout scans apple trees with cameras in order to estimate crop load, and is the first step in the development of a robotic harvester for fresh apples. Collectively with the other aspects of the “Comprehensive Automation for Specialty Crops” SCRI project, the Scout will help mechanize the growing of tree fruit. The goals for 2010 were to improve the apple detection and sizing accuracy for both red and green fruit, and to upgrade the prototype Scout’s robustness and operating scale.

The 2010 test results demonstrated significantly improved fruit detection and repeatability of performance. The field tests also showed that trees with lush canopies and a heavy crop load inhibit the Scout cameras from seeing the all the apples on the trees, biasing the scout estimates to be low. However, the crop load estimates for sections with verified hand counts were consistent and repeatable to within 10% across multiple trials. These results strongly indicate that the inclusion of a bias correction method will yield an accurate crop load estimate.

During the field tests, the Scout scanned 11.5 acres in two blocks, one with green apples and one where the apples had started to turn red. In the green block, the Scout counted 299,997 apples. The count after the bias correction was 560,358. In addition, the Commission hand counted apples in four 60’ sections within the block. For those sections, the ratios of the hand counts to the Scout’s count were 1.95, 1.71, 1.88 and 1.94, demonstrating the Scout's consistency. The raw median diameter estimated by the scout over the full green apple block was 2.62", while the median hand measured diameter over the 60' sections was 2.58", indicating that very little bias was present in the Scout's median size estimates. The scouting procedure was the same in the red apple block, and the results were similar. These results indicate that the Scout is capable of producing an accurate crop load estimate.

While providing absolute crop load estimates is essential, for the first time the Scout was able to show the apple distribution throughout a block. For the green apple block, breaking the 6 acres into 16’ sections showed that the apple counts in the sections had a median and standard deviation of 340 and 158.7 respectively. Ultimately, data such as these will help decrease the growing costs for tree fruit by enabling precision farming to better target efforts and costs only where they provide benefit.

Throughout the field tests, the Scout operated almost flawlessly, including operation in temperatures well in excess of 100°F, with no failures caused by heat or continuous operation for the computers, cameras or flash system. Also in 2010, VRC increased analysis speed by approximately 20 times, but still requires an additional processing speed increase of another 20-40 times to achieve real-time operation.

The next phase of development will move the Scout towards production. One key aspect of a viable product is a simple bias correction process. Growers cannot be expected to hand count small sections of each block to be scanned. Improving scouting performance will decrease the bias correction required. One technique that should significantly decrease the variability of the required bias correction across different orchards, tree configurations and apple varieties is for the system to determine how far it can thoroughly see apples in the trees being scanned, limit counting to that depth and directly scale the count proportional to the ratio of tree thickness to visible depth. A second key requirement for the Scout is to operate quickly and cost effectively in full size production blocks. This objective can be met by statistical sub-sampling the blocks. Thus, the plan for 2011 is to quantify and implement both bias correction and sub-sampling methods. Finally, in 2011, the Scout performance will be enhanced to accurately operate in a wide range of apple varieties and orchard configurations.

FINAL PROJECT REPORT

Project Title: Platform and bin filler technologies

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Other funding sources

Agency Name: USDA
Amount awarded: $5,900,000
Notes: Provided salary support for one graduate student (Brian Kliethermes)

Total Project Funding:

Budget History:

Item	**2009**	**2010**	
Salaries			
Benefits			
Wages			
Benefits			
Equipment		2,000	
Supplies	3,000	6,000	
Travel	500	1,500	
Miscellaneous			
Total	3,500	9,500	

PLATFORM TECHNOLOGIES

OBJECTIVES

1) Develop core team and identify needs and priorities including economics, health and safety
2) Identify current options for meeting specific needs (light duty, hybrid)
3) Begin initial design of light duty and or hybrid equipment or begin initial procurement of light duty and hybrid equipment
4) Determine best protocol for assessing multi row, over the row platform in the field

SIGNIFICANT FINDINGS

- Core WA team identified and expanded to include Penn State and MI State. Top priorities are ROI, Integration, Ergonomics, OTR and 2 person platforms.
- Options are being identified – domestic options are not fully commercialized, international options are on the shelf
- Designed and purchased Sensible Machine Inc. /Workman Toro Hybrid Platform. Still interest in SilverBull platform – will fully evaluate during Nov 2010 Italy study tour.
- SCRI proposal for OTR is under development. PD for project is Qin Zhang and includes WSU, ARS and MI State.
- SHIP Platform Ergonomic Project was funded and year one data collection is complete.
- ETV has successfully performed in research trials

RESULTS AND DISCUSSION

The platform technology portion of this project met its stated objectives in that several tasks were accomplished, resources were secured, equipment purchased and teams identified and partnerships built. Using both formal and informal methods, the priorities for platform research and development were identified as: ROI, Orchard/ Employee Integration, OTR, Ergonomics, and 2 person platform designs. The CASC technology adoption survey reports that serviceability and reliability are critical criteria that influence adoption of new technology. This is the case with mobile orchard platforms.

The UW SHIP proposal was funded and year one activities yielded industry partnerships and identified goals and objectives to be used in protocol development.

After researching our needs for a 2 person platform, PI worked with Sensible machines to have a 2 person platform built for use on the CASC Toro Workman / APM. Fig.1. This research vehicle will arrive in WA in January 2011. We continue to explore options for a commercially available 2 person platform. Our study tour to Italy will include the viewing and evaluation of the latest versions being sold in Europe. The development of Over the Row mechanization and automation technologies and is the subject of a 2011 SCRI proposal. The proposal also includes a novel apple orchard system /architecture component.

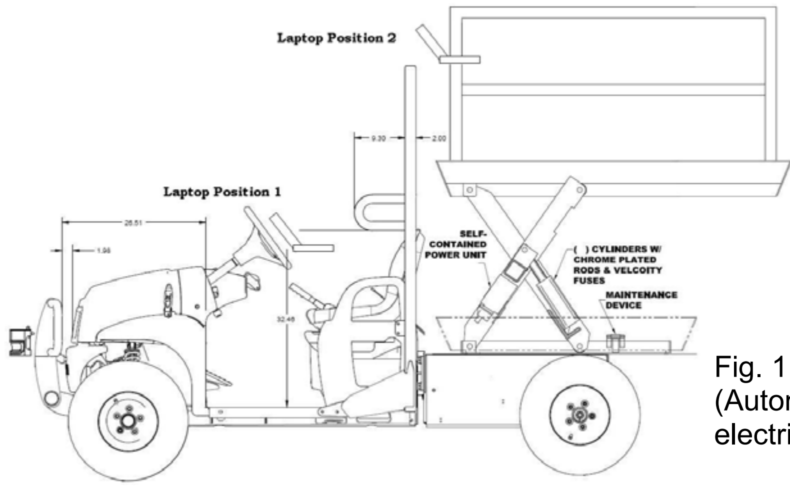

Fig. 1 Sensible Machine APM Platform (Autonomous Electric Toro Workman and electric scissor lift)

BIN FILLER TECHNOLOGIES

OBJECTIVES

1) Construct prototype of the Energy Absorbing Grate Bin Filler
2) Construct prototype of the Self Adjusting Bin Filler
3) Field test both bin fillers

SIGNIFICANT FINDINGS

Carnegie Mellon, Penn State, and ARS developed designs for two prototype bin fillers that showed promise in laboratory testing for reducing damage to fruit during the bin filling process.

- *Energy absorbing grate bin filler*—frames of energy absorbing materials strung on elastic bands. (Figures 2 and 4)
- *Pneumatically self-adjusting bin filler*—parallel inflatable soft polymer cylinders attached to a frame and of an external air supply for pneumatic inflating of the cylinders. (Figures 2 and 3)

We developed full scale prototypes to determine if they could be successfully adapted to use in the field to both reduce fruit damage and to increase the speed of harvest. We also investigated method for guiding tossed fruit to the bins.

Our major findings were the following.

- Both types of bin fillers can reduce bruising when apples are dropped into them one at a time, and they are position within 2-4 cm of the top layer of apples in a bin.
- A variety of different energy absorbing materials successfully reduced bruising, including large sheets of inexpensive industrial bubble pack.
- The pneumatically self-adjusting bin filler could not lift itself because of the compliance of the polymer cylinders.

- When apple were dropped into a chute leading to the bin fillers, the impacts between the apples in the chute and in the bin filler caused significant bruising.
- Nets for guiding apples into the bin show promise for reducing the need for picking bags.
- *Singulation of the apples during transport into and through the bin filler is essential to reduce bruising.*

RESULTS & DISCUSSION

Figures 1 and 2 show one instantiation of the energy absorbing grate bin filler. Figure 3 shows the concept for the pneumatic self-adjusting bin filler, and Figure 4 shows the test rig for the full scale prototype.

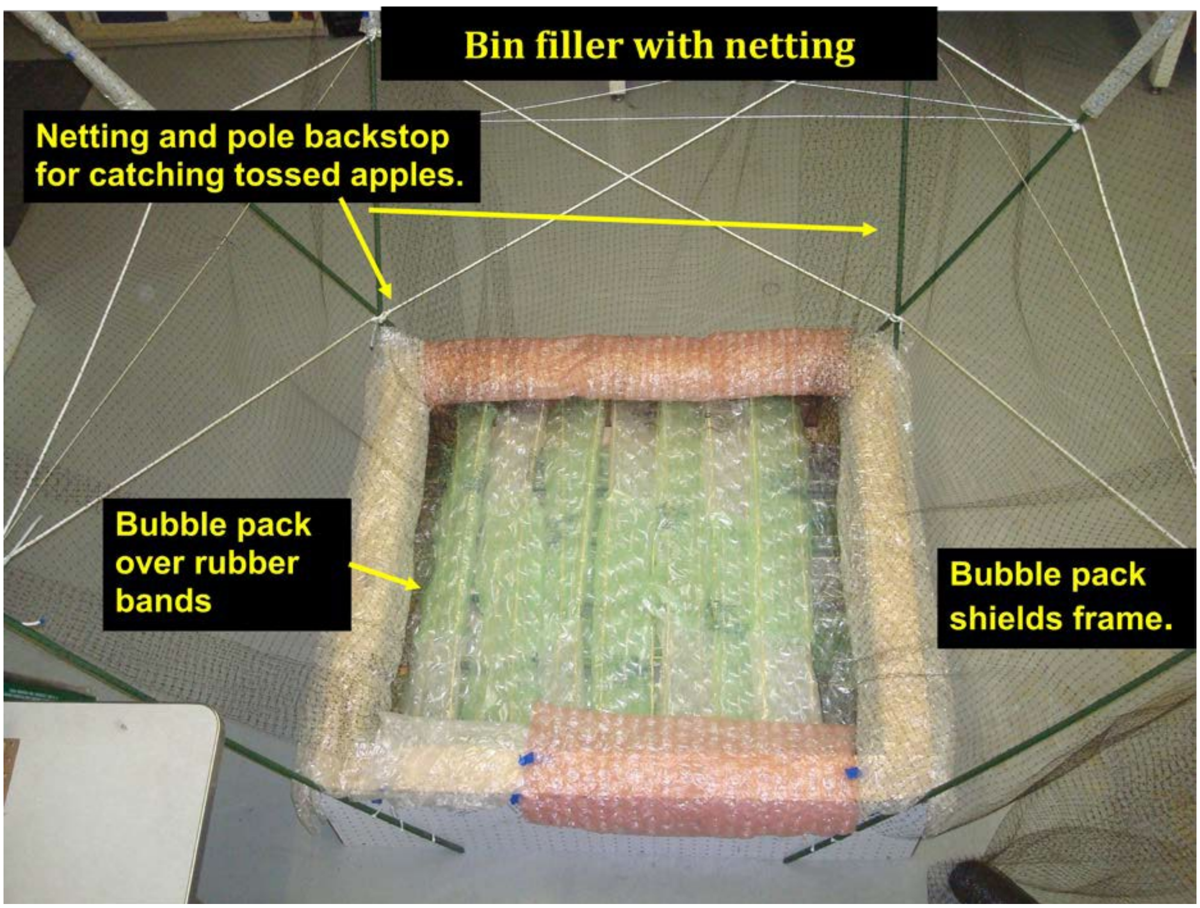

Fig. 1. Energy absorbing grate bin filler. Netting was experiment in guiding tossed apples into the bin filler.

We determined a variety of energy absorbing materials, such as foam balls strung on rubber bands, are suitable for the bin fillers themselves. Significantly, even inexpensive, easily replaceable bubble pack can work, provided the pressure in the bubbles is high enough and there is the right amount of space between the energy absorbers so that they slow down the apples without completely stopping them. (Figure 2.)

The pneumatic self-adjusting bin filler needs some modification to work as intended. The soft polymer cylinders are too compliant, and bend under the weight of the rest of the mechanism when inflated. The middle of a cylinder remains in contact with the central inflation tube, and thus cannot lift the mechanism. The solution may be as simple as tying off the cylinder into discrete, separately inflatable sections.

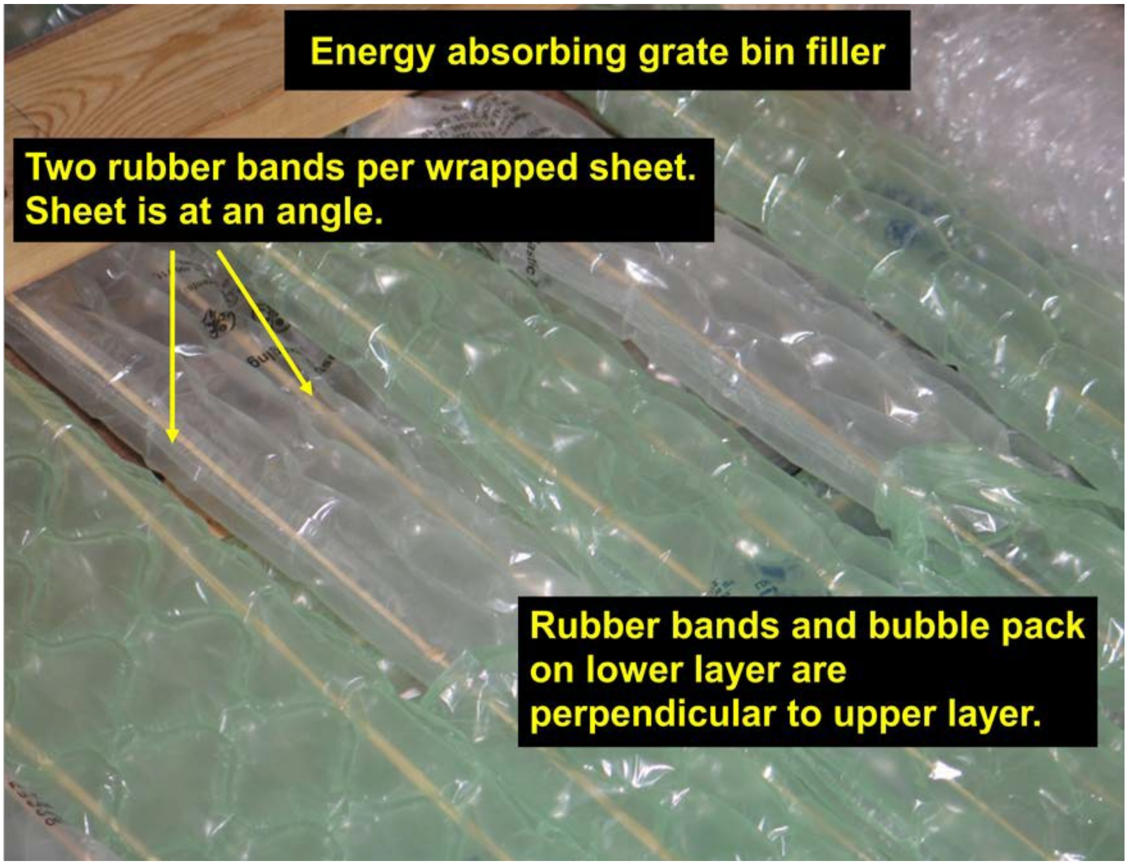

Figure 2. Energy absorbing grate bin filler with bubble pack

Both types of bin fillers were effective at reducing as intended when apples were dropped one at a time into the bin filler with enough time between successive drops to prevent apples from hitting each other. However, simply pouring a bag of apples into the bin filler from the side or into a chute leading to the bin filler resulted in excessive bruising. (Figure 4.)

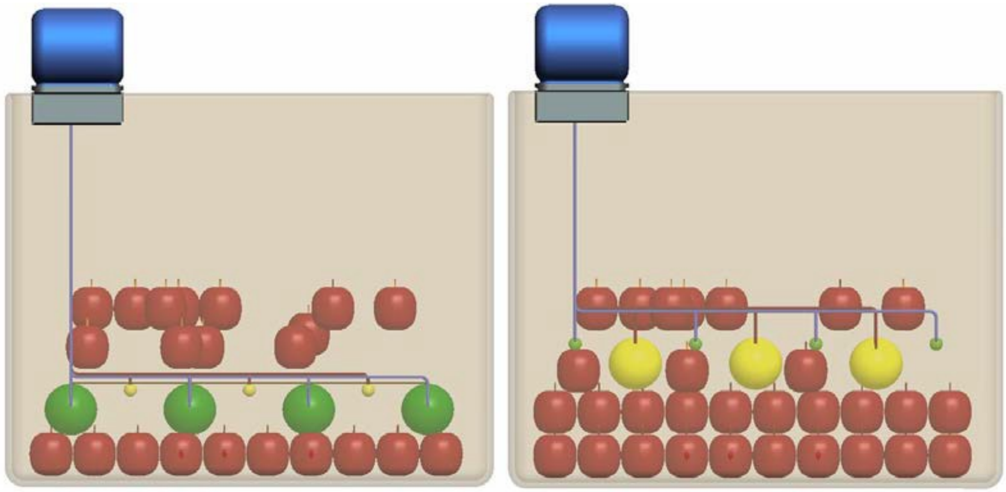

Fig. 3. Pneumatic self-adjusting apple bin filler concept

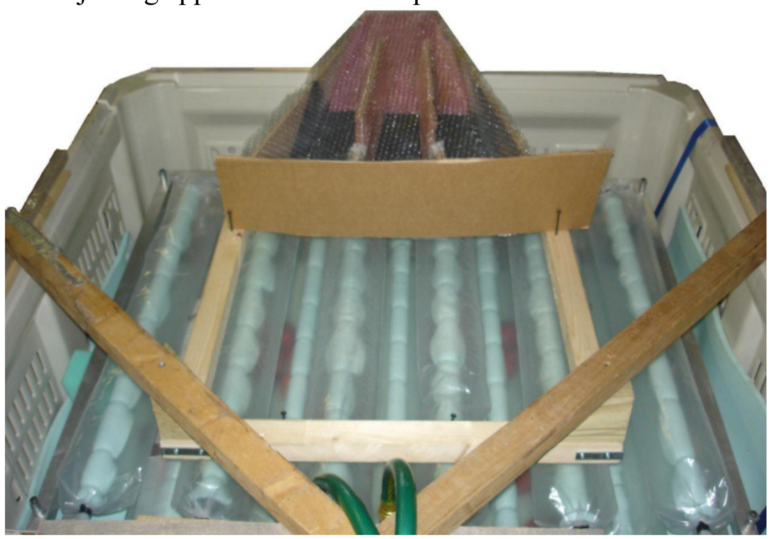

Fig. 4. Pneumatic self-adjusting bin filler with test ramp.

To address the problem of singulation, we also tried a system of netting to catch and guide apples into the passive bin filler. (Figure 1.) This method still had excessive bruising, but the problem was with impacts between the apples and the sides of the bin filler. There was insufficient padding on the edges of the bin filler and the netting did not sufficiently guide the apples to the middle of the bin filler away from the edges. Considering that apples were tossed from heights above 1.8 m (6 feet), the fact that the apples survived at all was encouraging. We believe this concept hold considerable promise for moving apples from the tree to bin without bags.

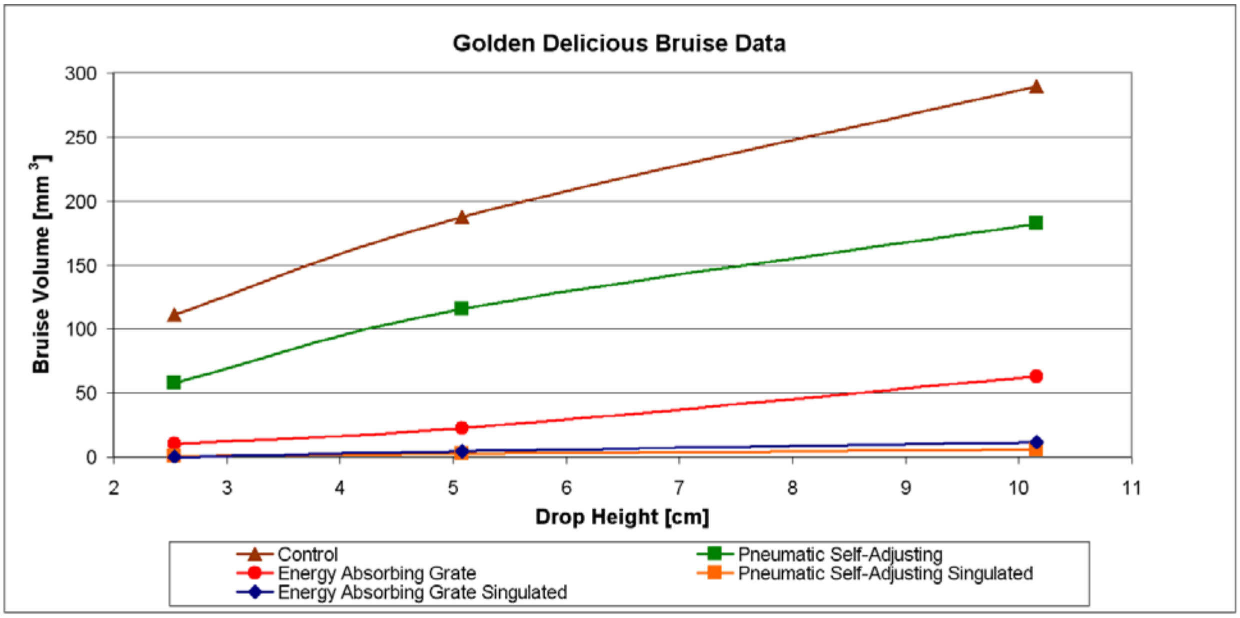

Fig. 4. Trend lines comparing the performance of two full-scale bin filling prototypes across three drop heights with and without singulation. Singulation improves performance by a factor of 10 for the energy absorbing grate and by a factor of about 100 for the pneumatic self adjusting bin filler.

EXECUTIVE SUMMARY

Platform technology is of great interest to the U.S. tree fruit industry. In Washington, we have brought new people to the table to address the many issues and challenges that influence purchase and adoption of platform technology. New WSU scientists that have taken on platform technology projects include Qin Zhang, Manov Karkee, Mykel Taylor and Karina Gallardo. Based on industry priorities we have identified a suitable 2 person platform, we have purchased a research vehicle with a 2 person platform, we have built a team to address OTR technologies and we there is a UW SHIP comprehensive platform ergonomic study funded and ongoing.

Significant activities and findings include

- Core WA team identified and expanded to include Penn State and MI State. Top priorities are ROI, Integration, Ergonomics, OTR and 2 person platforms.
- Identified platform equipment that is suitable for modern WA Orchards. Interest exists in the Italian SilverBull machines
- Designed and purchased Sensible Machine Inc. /Workman Toro Hybrid Platform.
- SCRI proposal for OTR is under development. PD for project is Qin Zhang and includes WSU, ARS and MI State.
- SHIP Platform Ergonomic Project was funded and year one data collection is complete.

Bin filler technology is the focus of several public and private studies. The process of filling bins is a bottleneck for the efficient harvest of apples. Carnegie Mellon, Penn State, and ARS developed bin filler designs and built full scale prototypes to determine if they could be successfully adapted to use in the field to both reduce fruit damage and to increase the speed of harvest. We also investigated method for guiding tossed fruit to the bins.

- *Energy absorbing grate bin filler*—frames of energy absorbing materials strung on elastic bands. (Figures 2 and 4)
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- *Singulation of the apples during transport into and through the bin filler is essential to reduce bruising.*

FINAL PROJECT REPORT
WTFRC Project Number: TR-10-104

Project Title: Digital traps for automated monitoring of insect populations

PI: Johnny Park
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Cooperators: None

Total Project Request: **Year 1:** $64,950

Other funding sources: None

WTFRC Collaborative expenses: None

Budget 1
Organization Name: Spensa Technologies, Inc **Contract Administrator:** Johnny Park
Telephone: 765-714-2379 **Email address:** johnny.park@spensatech.com

Item	Year 1
Salaries	34,000
Benefits	13,600
Wages	
Benefits	
Equipment	
Supplies	1,600
Travel	800
Miscellaneous	
Total	**50,000**

Budget 2

Organization Name: WSU-TFREC
Telephone: MLB 509-335-7667
KL 509-663-8181 x221

Contract Administrator: Mary Lou Bricker, Kevin Larson
Email address: mdesros@wsu.edu
kevin_larson@wsu.edu

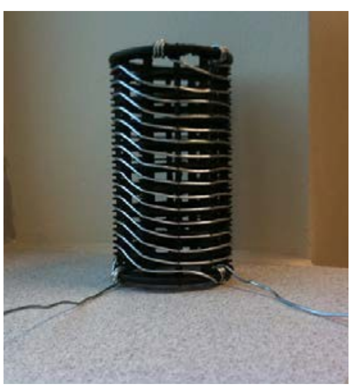
Item	Year 1
Salaries	10,500
Benefits	4,200
Wages	
Benefits	
Equipment	
Supplies	250
Travel	
Miscellaneous	
Total	**14,950**

Objective1. Devise an electrical discharge system for killing target insects entering the trap: (i) Determine optimal voltage and current levels for killing codling moths and other major pests; (ii) Investigate various features that can be extracted during electrical discharge for possible identification of insect species.

We have devised an electrical discharge grid (or "zapper") that consists of a pair of metallic wires rolled around a cylindrical plastic grid spaced 1/5" apart from each other. Figure 1 (left) shows a picture of the first version of grid. Ten prototypes of the grid were constructed for use in our experiments. Although the initial electrical discharge grid design performed satisfactorily under most conditions, during the experimental evaluation we learned that in the presence of water or certain chemicals (such as the stannic oxychloride used to visualize air flow in the wind tunnel), the plastic frame that was used to support the wires that form the electric discharge coils would become conductive and short circuit the two terminals of the device, impairing its functionality. Additional laboratory experiments revealed that several chemicals commonly used in agriculture had a similar effect and some of these chemicals were very hard to remove from the plastic frame (Table 1). In addition, the plastic frame was sometimes used as a landing surface by the target insects, which would not get electrocuted because they would not touch the wires. For these reasons, we devised a new electric discharge grid that consists exclusively of two conductive coils without a plastic frame, as illustrated in Figure 1 (right). The new design successfully solved both problems.

Table 1: Results of laboratory experiments about the effects of chemicals on the zapper grid with plastic frame.

Chemical	Amount needed to short-circuit the grid	Difficulty to remove
Surround	Small	Medium
Damoil	Small	Hard
Lime Sulfur	Small	Easy
Micro Sulf	Small	Hard
Cuprofix	Small	Medium
Captan	Large	Easy
Calcium Chloride	Large	Easy
Penncozeb	Small	Easy
Stannic Oxychloride	Small	Very Hard
Water	Medium	Easy



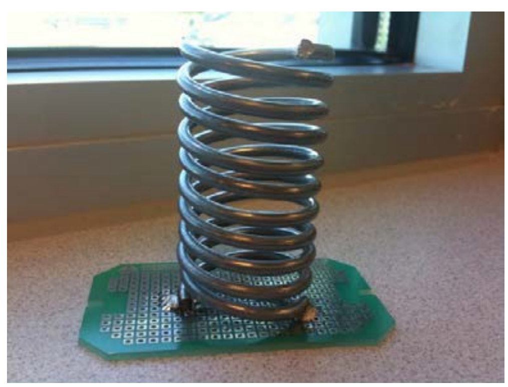


Figure 1: Initial electrical discharge grid with plastic support frame (left). New electrical discharge grid without plastic support frame (right).

We also designed and implemented a high-voltage electronic circuit that allows a digital microcontroller to adjust the voltage applied to the grid. The circuit allows the voltage applied to the zapper to be varied

by small increments up to several hundred volts. Several units of this circuit were constructed, and were used to evaluate the electric characteristics of the signal required to effectively electrocute and count the adults of codling moth (CM), oriental fruit moth (OFM), and obliquebanded leafroller (OBLR).
In addition, we designed a data acquisition circuit for measuring the voltage applied to the grid. By observing the variation in the signal, the digital microcontroller is able to detect when a moth touches the grid. The time stamp of the detection is reported to the user via a wireless communication link. False detections caused by electric variations of the system (i.e., noise) were eliminated by the use of a median filter. Figure 2 shows the signal generated by the zapper during normal operation and the electric spike generated by the detection of a target insect. The solid line corresponds to the unfiltered signal, and the dashed line represents the signal after application of the median filter. As the figure shows, the small electric variations of the signal are completely removed by the median filter, whereas the large variations that occur during an insect detection are retained.

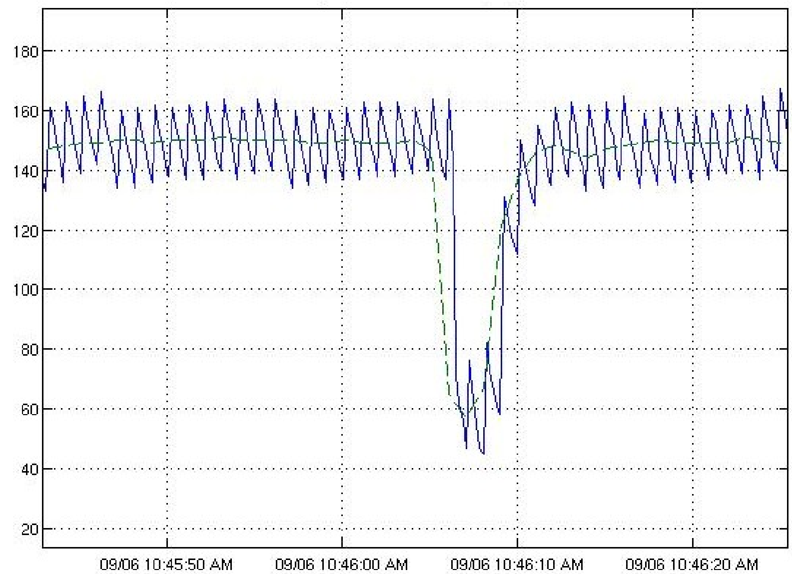


Figure 2: Electric signal generated by the zapper grid (solid line) and result of applying a median filter to the signal (dashed line).

As we carried out experiments to find the optimal voltage levels to kill the target insects, we realized that although it is possible to kill all target insects by applying reasonable voltage levels to the discharge grid, the carcass of the killed insect would often stick to the grid and cause a short that was only cleared by carbonization of the insect. To mitigate this problem, we decided to integrate the results obtained in Objectives 1 and 2 (described below) and instead of killing the insects, we used the electric discharge to simply temporarily stun them so that they would fall inside the collector and would not be able to leave it because of the baffle. Figure 3 (left) shows a schematic diagram of the new design for the electric discharge grid based trap, or zapper trap.
Based on several laboratory experiments, we found voltage levels that allow the target insects to be temporarily stunned whenever they contact the electric grid without sticking to its surface. For both CM and OBLR, the average voltage level is ≈750V whereas for OFM it is ≈450V.
Although the initial estimate of the lifespan of the electronic circuits developed was ≈700 hours with 4 D-type batteries, this estimate was based on assumptions that proved too optimistic. The latest version of the circuits presented a measured lifespan of ≈400 hours operating with 6 D-type batteries. However, this lifespan was achieved without employing any sophisticated power saving mechanisms. Further investigation of power saving methods as well as the integration of solar power harvesting devices will allow for a significant increase in the current lifespan.

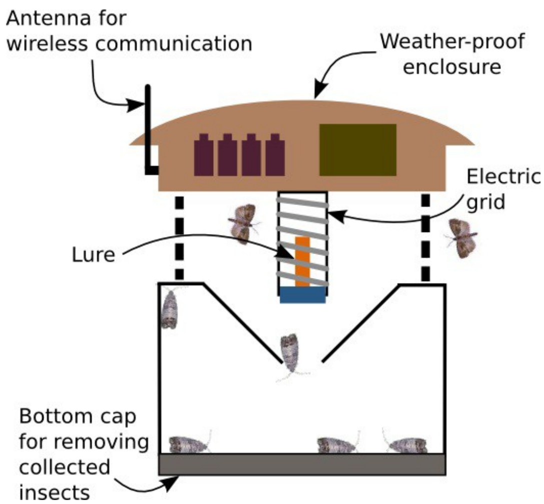


Figure 3: Zapper trap schematic diagram (left). Wind tunnel experiments with zapper trap prototype (right).

After finding the optimal voltage levels for the detection of the different insect species, a prototype was built and tested in the wind tunnel at the Washington State University Tree Fruit Research and Extension Center (WSU-TFREC) in Wenatchee, WA with adult CM and OFM. Figure 3 (right) shows a picture of the wind tunnel experiments. The experiments showed that the zapper trap is capable of accurately counting the number of insects captured, obtaining nearly 100% detection accuracy in this controlled environment.

Given the successful experiments with the first prototype of the electric grid based trap, we designed a weather resistant enclosure for the trap based on off-the-shelf components to be used in small scale field tests. **Error! Reference source not found.** (left) shows an image of the new model of the zapper trap.

Figure 4: Second prototype model of the zapper trap (left); Second prototype of the zapper trap deployed in a WSU-TFREC orchard for field testing (right).

In June 2010, ten zapper traps were deployed in an experimental orchard at the WSU-TFREC and ten additional traps were deployed at the Pennsylvania State University Fruit Research and Extension Center in Biglerville, PA. **Error! Reference source not found.** (right) shows one of the traps deployed at Washington. For a period of three months, the traps were used to monitor the population of CM and OFM in the orchards. During this period, the performance of the traps was carefully monitored and the data generated by each trap was collected periodically. For comparative purposes, the same number of standard delta traps was deployed in nearby locations in the orchards.

Although the zapper traps proved functional and operated uninterruptedly without major problems for the entire test period, they achieved significantly lower capture rates than those of the standard delta traps. This is in contrast with the results of the wind tunnel experiments carried out at WSU using the first prototype trap (Figure 3), which achieved a comparable, if not better, capture rate than the conventional delta traps. We believe that the exterior shape of the current trap is somehow disrupting the dispersion of the pheromone plume.

We evaluated the initial trap design in the wind tunnel and in the field. In the field, during the month of July, the original trap design caught between 8 and 11% of the moth catch of standard delta traps. In the wind tunnel, we used smoke (i.e., stannic oxychloride) to evaluate the pheromone plume emitted from the trap. We found that the shape of the trap caused a vacuum downwind from the large top, which caused the pheromone to curl back to the top, so that moths spent more time around the top of the trap and did not approach the zapper coil. The lower part of the trap was also problematic, because moths that went below the bottom part of the trap also lost the pheromone signal and were unable to locate the plume again, which resulted in the moths staying below the lower disk.
In order to identify and understand the reasons behind the low catch rate of the new trap prototype, several modifications to the design of the external structure of the trap were evaluated, some of which are shown in Figure 5. We tested eight different modifications of the trap either by modifying the bottom, or by incorporating portions of a bucket trap, which appeared in the wind tunnel to improve airflow around the trap and trap catch. We also evaluated two other modifications, one a bucket trap with the zapper coil attached at the top, and the other a delta trap attached over the coil, as illustrated in **Error! Reference source not found.**. Because we only had a limited number of traps to test, these parts of the test were replicated only over time. From early August to September 8, we were able to release large numbers of sterile CM from Canada roughly once a week in an orchard adjacent to the lab at the WSU-TFREC.

Figure 5: Experimental trap exterior designs.

Figure 6: Modified zapper traps employing existing bucket trap (left) and delta trap (right) exterior designs.

In the field, we found that the bucket trap modified with a coil (Fig. 6 left) captured ≈56% (85 moths) of the total delta trap capture (152 moths), and on most days was within 1-2 moths of the delta trap. However, on one date when the delta trap was placed high in the tree (instead of the same level as the electronic trap), trap capture was roughly 2.5 fold higher (62) than the bucket trap modification (24). In the WSU-TFREC experiments, the delta trap modification was less successful, at least in part because the coil was smaller gauge wire and was easily distorted by the trap and potentially resulted in a short of the zapper. The other modifications were consistently less efficient than either the delta or bucket modifications, despite not having the same issues with the coil.

The bucket trap modification shows the potential of the zapper, and would easily allow for the combination of the zapper with the IR traps tested last year. Future designs of the zapper should simply place the electronics into a convenient, water-proof enclosure with the zapper coil on a cable that can be attached to whatever trap design works best. We anticipate that this design could be easily tested in the lab wind tunnel during the winter and modified relatively easily without having to re-engineer the trap design.

Figure 7 and Figure 8 show some quantitative results obtained in the orchard at PSU. The figures show the cumulative capture of two modified zapper traps with delta bottoms as well as the corresponding nearby standard delta traps used to evaluate the efficiency of the zapper traps. Figure 7 shows the capture of OFM, and Figure 8 shows the capture of CM. As Figure 7 shows, the number of OFM captured in the modified zapper trap with the delta bottom (Fig. 6 right) easily surpassed the number captured by the manual delta trap. In Figure 8, the large increase in the number of CM detected by the manual delta trap between September 5 and 7 corresponds to a period of increased flight of CM adults in the orchard, which was similarly observed in other traps. Unfortunately, the corresponding zapper trap was inadvertently turned off (i.e., likely due to wind pushing the trap against a branch and turning off the trap) at some time during this period, and hence it did not capture moths during this heightened flight period. The total number of moths captured by the zapper trap then amounted to approximately 51% of the total number captured by the corresponding delta trap.

Because of the limited number of traps available and the high number of parameters that needed to be evaluated (e.g., trap exterior design, zapper coil shape and size), the experiments could not be replicated. However, the longitudinal assessment of the traps indicates that the delta and bucket designs integrated with the zapper are very promising, and the capture rate of the electronic trap may become even higher than the capture rates of existing manual delta or bucket traps. Further research would be required, however, in order to produce more conclusive quantitative results with statistical significance.

In addition, improving the zapper trap exterior for the purpose of increasing its capture rate during the field tests conducted at WSU and PSU, allowed us to collect additional electronic and environmental data. This data, in addition to the signal generated by the detection of CM and OFM, includes signals caused by the capture of different kinds of non-target insects as well as environmental phenomena of varying intensity, from light rains to severe storms, to spraying the traps every 7-10 days with fungicides (PSU). The data collected is accompanied by ground truth information based on the daily observations made in the field. That is, along with the digital signals obtained by the sensor, the data includes the number of target and non-target insects captured by each trap as well as the corresponding weather information.

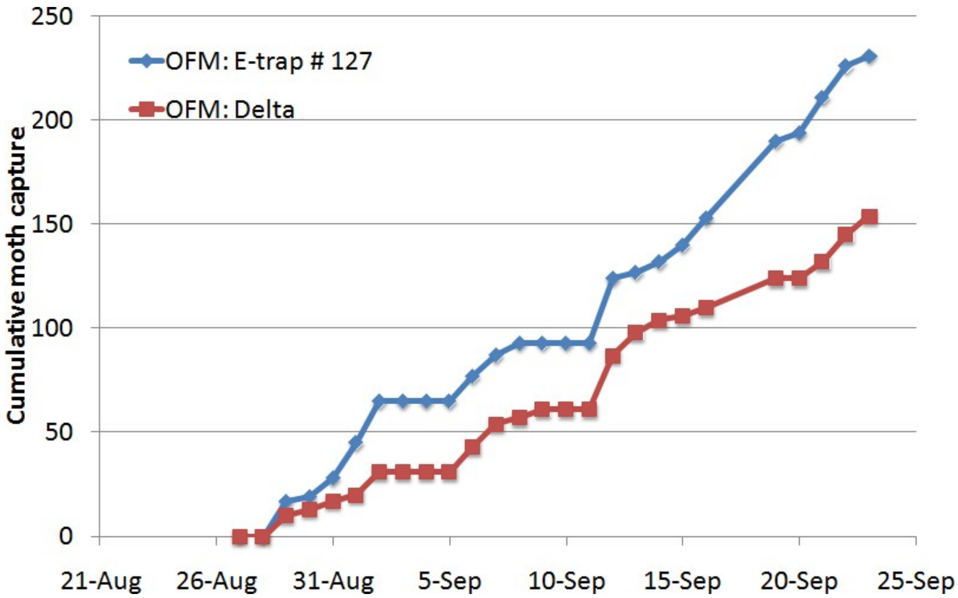


Figure 7: Cumulative OFM capture of one of the zapper traps (E-trap #127) with a delta bottom compared with the captures of a nearby large delta trap.

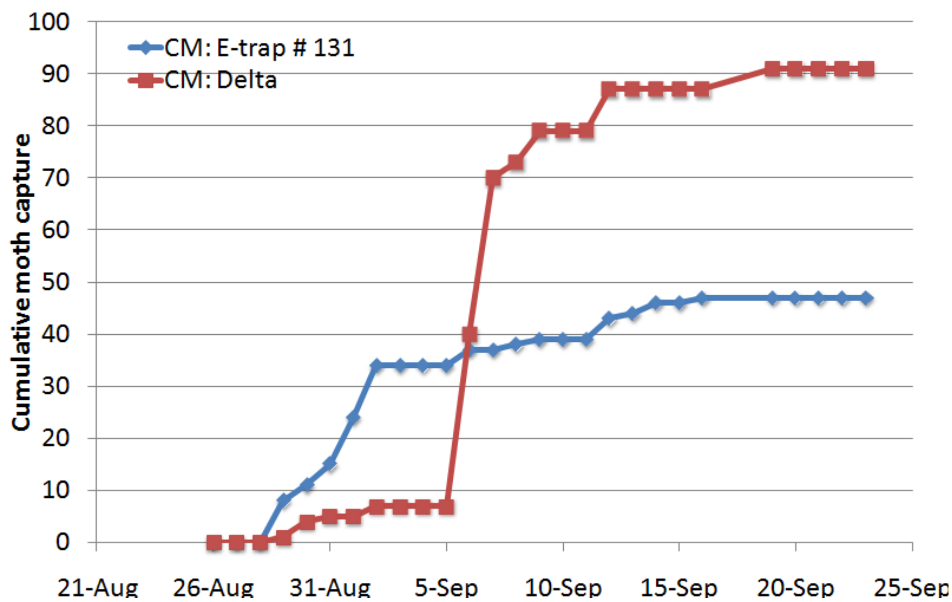


Figure 8: Cumulative CM capture of one of the zapper traps (E-trap #131) with a delta bottom compared with the captures of a nearby large delta trap. Between September 5 and 7, there was an increased flight of CM adults in the orchard. Unfortunately the zapper trap was inadvertently turned off during that period causing a large discrepancy in the number of captured CM adults.

Unlike the signal obtained in the wind tunnel experiments, which contained only target insect detections, the signal obtained in the field experiments also contained a great amount of irrelevant events caused by things such as non-target insects, meteorological conditions or a spraying event. For that signal to be used to count the number of detected pests, it must be pre-processed in order to remove the perturbations generated by the irrelevant events. Figure 9 shows one example of the distinct signals generated by the detection of a target insect and the signal generated by a non-target insect. It is clear from the figure that the response of the zapper varies significantly for different events. Similar situations are observed, for example, in signals generated by rain or a spraying event.

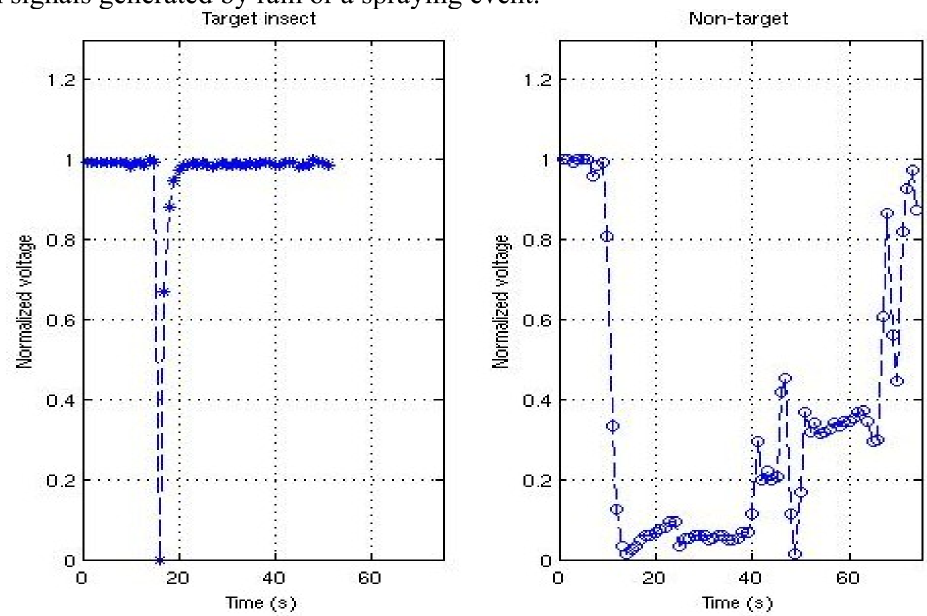


Figure 9: Measurements of the zapper signal generated by a target insect and a non-target event.

Although it is easy for the human eye to recognize signals generated when target insects are detected, designing algorithms that filter irrelevant events is not trivial. Multiple measurements of the same insect species may differ slightly due to environmental conditions and to small variations in the physical characteristics of individual members of a given species (e.g., size). It is thus necessary to identify the common features of every event generated by a target insect as opposed to undesirable events in order to develop more effective digital signal processing methods for filtering irrelevant events.

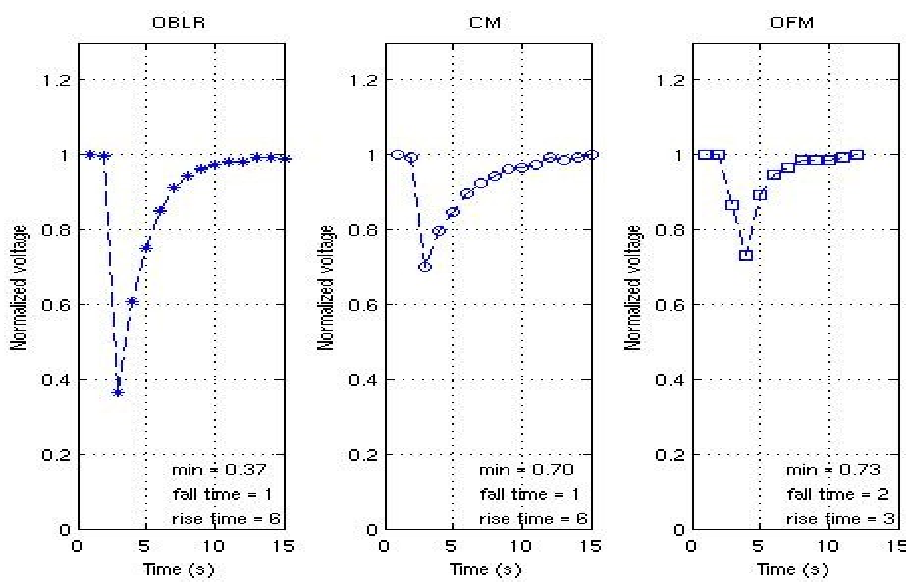
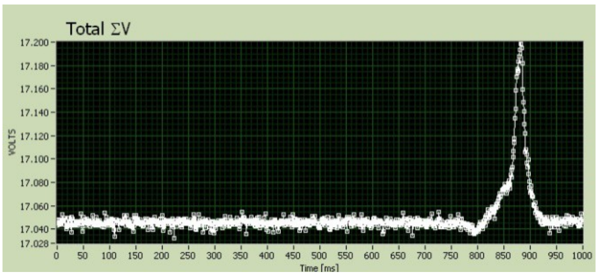


Figure 10: Electric pulses generated by the detection of the three different target insects.

The signals generated by different target insects also present distinct characteristics, as illustrated by the example shown in Figure 10, which compares the electric pulses generated by the detection of OBLR, CM, and OFM. Although these examples are encouraging, they should be no means be considered as general representatives of the corresponding insect species. In order to extend these results and design

effective detection algorithms based on them, a more rigorous evaluation of the variability of the detection signal within each insect species is required.
In addition to the zapper voltage measurements, insect species identification may be made more accurate if multiple sensing sources are employed. We could, for example, integrate the zapper with the infrared sensors of our previous trap and use both signals simultaneously to identify the detected insect. From our previous experience with the IR-based traps, we believe the amplitude and the width of a peak generated by IR sensors are best suited for both insect identification, as shown in Figure 11, but other possibilities could also be explored.



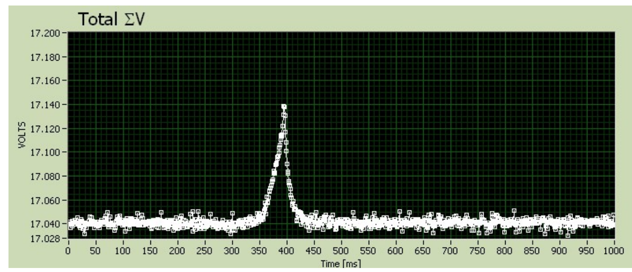


Figure 11: Signal response when an adult codling moth passes through the IR sensor funnel (left); Signal response when an adult Oriental fruit moth passes through the IR sensor funnel (right).

It is important to note, however, that processing and analyzing the massive amounts of data produced during the field experiments is a formidable task. The information obtained by the traps consists of hundreds of millions of data points and several thousands of events of interest. Just to put in perspective, using a regular laptop computer, it takes approximately 10 minutes simply to load and plot the data corresponding to 2 weeks of monitoring by a single trap. Manual inspection of the data allowed us to initially identify some of the signal features such as pulse width and slope that could be employed to distinguish between target insects, non-target insects, or irrelevant events, but developing algorithms to carry out these tasks and robustly filter out undesired data will require further investigation.
To visualize the insect detections during the field tests, an experimental web-based graphical user interface was designed. Whenever a trap detected an event, a message was transmitted to the base station computer. The message contained the trap ID, the total number of events detected by the trap, the detection timestamp (date and time) and the minimum voltage level of the detected pulse. This information was then stored in a database and displayed in the user interface. However, during the field experiments, the user interface proved somewhat limited especially when multiple incorrect detections took place (e.g., during rainy periods) because navigation through the available data was somewhat difficult. Further research and development is thus necessary in order to design a more user-friendly interface. We believe that an interface that would show the geographical location of the traps in a map and would allow the user to select individual traps to inspect the detections would greatly improve the overall usability of the system.

Objective 2. Design trap interior that would prevent insects from flying up and down through the sensors. We built a clear acetate trap that allowed us to use video analysis of moth behavior within the wind tunnel. Our initial interior design, shown in Figure 12, allowed us to move a cone up and down within the funnel of the trap to prevent moths from flying back up towards the sensors. This design is based on the inability of a moth to hover during flight. However, in our experiments we learned that if the cone of the funnel was a reasonable size, this modification was not required. It was required on the IR traps used last year, because the funnel was shortened, which made the opening larger to insert the electronics in the trap. In our traps this year, in both the lab and the field, we found that the normal size funnel is all that was required.

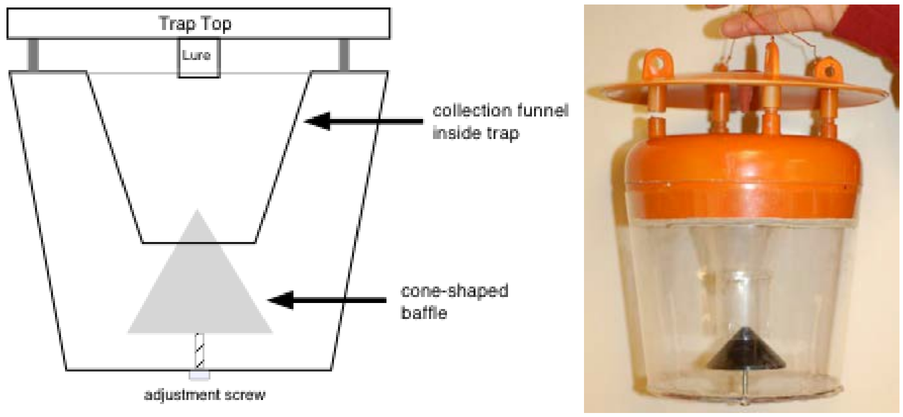


Figure 12: Trap interior design for preventing moths from flying up and down through the sensors

A preliminary laboratory study was conducted at PSU to understand if the size of the funnel opening at its base is important in preventing CM and OFM moths from escaping from the zapper traps since the moths are only temporarily stunned when touching the coil. When the funnel opening inner diameter was 27 mm (i.e., the size of opening included in the initial prototype design), significantly more OFM moths (38.3% escape rate) were able to escape upward through the funnel opening than CM moths (13.3%) over a 24 hr period. When we reduced the funnel opening to 13 mm (ID) on all modified zapper traps at PSU, we still observed some OFM adults escaping upward from the collector. More studies are needed to select the correct inner diameter opening of the funnel to minimize moth escape in the orchard.

Objective 3. Investigate the effects of electronic components towards the behavior of moths, e.g., size of area affected, frequency sensitivity, etc.

All tests performed this year with the IR traps showed no effect of the electronics on the moths in the wind tunnel. In our trials, we placed a piece of hardware cloth on top of the trap opening and coated the hardware cloth with sticky material. We then used a low load CM lure placed on the hardware cloth. In 13 trials in December through February, we released moths in the wind tunnel with the traps present. Video analysis and catch on the hardware cloth did not reveal any observable difference when the electronics were on or off. We also have video that showed high activity around the lure when the trap was on – this strongly suggests that the effect in the field was not auditory, as the lure was directly over the cone shape collection funnel where presumably the effect would be quite strong.

Initially, we thought that the methods that we were using to turn on different parts of the electronic circuit during the on/off studies were defective, however, the trap was shipped back to the Spensa group, which checked them and installed LEDs so that we could be sure which parts of the trap were turned off. Further video analysis did not show any noticeable effects of the electronics. We are still unsure why the IR traps did not catch any CM in WA or PA last year. Possibly, it could have been from the moths exiting the traps, because of the different shape of the funnel necessary for the installation of the electronics (see Objective 2 for more details on findings about funnel size) or it could have been due to the inclusion of the Vapona® strip (i.e., killing agent to knock down moths within the funnel). It is very clear, however, that the electronic circuits did not have any noticeable effect on the behavior of either moth species.

Executive Summary

The project described in this report represents significant progress toward the goal of automating the monitoring of pest insect populations in apple orchards. It consisted of three main objectives, each of which assessed the viability of a different component required by an electronic system to automatically detect target insects. The technologies developed in this project were designed for three main target insects: codling moth (CM), oriental fruit moth (OFM), and obliquebanded leafroller (OBLR).

In the first objective, an electric discharge grid (or "zapper") was developed for the purpose of stunning the target insects and simultaneously detecting the electric discharge to count the number of insects captured. During this project, in addition to developing the discharge grid itself, we also designed the electronic circuits necessary to generate the electric charge and to measure the discharge. In addition, we designed a digital circuit that automatically transmits the detections to a computer via wireless communication. A trap prototype using the designed circuits was constructed and evaluated in the wind tunnel with outstanding results (practically 100% detection rate).

Different models of the electronic trap were constructed and tested in the field. In addition to several variations of the exterior model designed specifically for the zapper trap, we also experimented with delta traps and bucket traps retrofitted to include the zapper and the electronic circuits. We learned that the trap exterior design had a great impact on its insect capture rate. Of all the trap models evaluated, the standard delta traps and bucket traps modified to include the zapper grid and corresponding electronic circuits obtained the best capture rate. The traps were evaluated in orchards in WA and PA from early August to late September.

All of the data generated by the traps in the field were collected and analyzed. As expected, we observed that in the field, unlike in the wind tunnel experiments, the data presented several undesired events caused by different factors such as rain, fungicide spraying, and the capture of non-target insects. Based on the information collected, the signal characteristics were analyzed and simple algorithms were developed to distinguish the events caused by the detection of target insects from irrelevant events. However, this task requires much more careful evaluation and identification of common signal features from the tens of millions of data points collected in the field. Although preliminary qualitative results were obtained, further research is required to create robust algorithms that can count target insects with acceptable accuracy in the field. For the next generation of automated traps, we will consider the possibility of including optical measurements (e.g., IR) as a second source of target insect detection.

In the second project objective, we designed and evaluated insect collectors that can be used in the proposed automated traps. The main goal was to design collectors that would allow temporarily stunned insects to enter easily but that would not permit the insects to exit. Our experiments showed that a simple funnel placed below the stunning element (the zapper in this case) and above the collector entrance is generally enough to prevent insects from escaping the collector, as long as the funnel opening dimension is appropriately chosen. We were able to obtain negligible escape rates for CM. Although we also made significant progress in reducing the escape rate of OFM, we believe further research is necessary to identify the optimal opening size. As OBLR is larger than CM, if CM cannot escape, it is unlikely that OBLR could.

Finally, in our third objective, we evaluated the effects of electronic circuits on the behavior of adult codling moth and oriental fruit moth. We assessed the response of the different insect species to the auditory, visual and electromagnetic effects of the electronic circuits. Our experiments showed no noticeable effect of the electronics on moth behavior. Further studies would be required to precisely identify the reason for the absence of captures in the experiments with the IR traps from the previous year, but we believe it may be related to the size of the funnels used in the trap collectors or a possible repellent effect of the Vapona® strips used to kill the collected moths.

CONTINUING PROJECT REPORT **YEAR:** 1 of 3
WTFRC Project Number: TR-10-101

Project Title: Evaluation of environmental data used for IPM models

PI: Vincent P. Jones
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Cooperators:

Total Project Request: **Year 1:** $ 58,432 **Year 2:** **$47,031** **Year 3:** **$**48,965

Other funding sources: None

WTFRC Collaborative expenses: None

Budget 1
Organization: WSU-TFREC **Contract Administrator:** Mary Lou Bricker, Kevin Larson
Telephone: 509-335-7667/663-8181 x221 **Email:** mdesros@wsu.edu / kevin_larson@wsu.edu

Item	2010	**2011**	2012
Salaries[1]	24,622	**28,833**	29,986
Benefits [2]	7,810	**12,948**	13,466
Wages	0	**0**	0
Benefits	0	**0**	0
Equipment [3]	21,000	**0**	0
Supplies	3,000	**3,150**	3,308
Travel [4]	2,000	**2,100**	2,205
Miscellaneous	0	**0**	0
Total	58,432	**47,031**	48,965

Footnotes:
[1]4 months Ute Chambers (Y1-Y3), 2 Months T. Melton Y1, 3 Months Y2-3
[2]Ute Chambers 32%, T Melton 30.9%
[3]Weather stations and sensor costs
[4] within-state travel

Objectives:

Evaluate the validity of virtual weather stations using a combination of regional and site-specific (in-orchard) weather monitoring systems and NOAA site-specific forecasts.

Evaluate the differences between AWN and within-orchard environmental conditions on model accuracy.

Compare the effect of high and low-density plantings as well as overhead cooling on environmental monitoring and how those horticultural and operational changes affect model accuracy.

Significant Findings:

For the codling moth and peach twig borer models, the NOAA corrections appear to work from year to year. Other models will be reported on at the next meeting.

Error rates for the corrected NOAA data appear to be flat throughout the season at ≈ 1 day, whereas they increase without the data correction.

Environmental conditions within the orchard differ from AWN data, even though the orchards were in close proximity to the AWN stations. Air temperature differences between orchard interior and AWN data resulted in deviating model predictions.

Methods:

Objective 1 - Virtual Weather Stations. We stored the site-specific forecasts from NOAA for each of the 132 WSU-AWN stations for 2009 and 2010. Additionally, we received weather data for 2010 from independent stations maintained by Wilbur-Ellis. For these stations, we calculated the degree-days for all the insect models and determined the error in terms of days when key population events would occur between the NOAA and in-orchard weather stations.

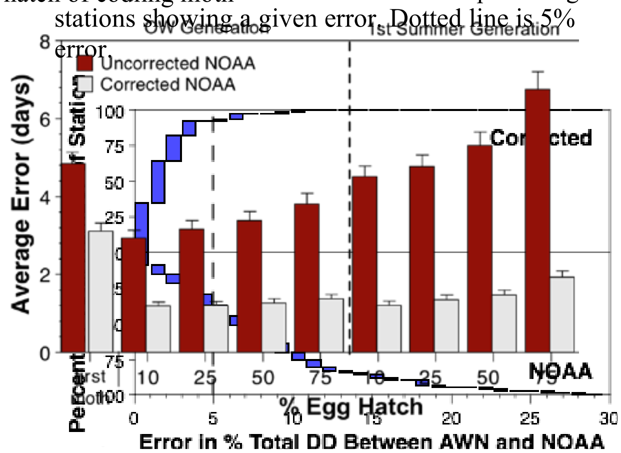
Objective 2 - Comparison of microclimate and model output between AWN data and orchard interior. We evaluated the differences between AWN weather data and environmental conditions in the orchard interior and how these differences affect model accuracy. Weather stations were set up in five apple orchards adjacent to AWN stations (WSU TFREC, WSU Sunrise, Malaga, Cashmere, and Quincy) between March 22 and April 5, 2010. These stations record air temperature within the canopy (2 m above ground), bark temperature (0.5 m), relative humidity within the canopy, solar radiation above the canopy (3 - 6 m), and leaf wetness (2 m). The microclimate parameters are measured every minute and averaged over a 15-minute period. The differences between AWN and orchard interior data were calculated, and the hourly averages were summarized for each month. Differences in model predictions were evaluated for seven insect models that use maximum and minimum daily temperature.

Results:

Objective 1 - Virtual Weather Stations. Recall last year that we had found in 2009 that we could correct NOAA data to predict AWN data, but that our concern was that the regression used to correct the data needed to be consistent from year to year. This year, we recorded both the AWN and NOAA data for 2010 as well as NOAA data from the Wilbur-Ellis stations in the Yakima area (encompassing Yakima, part of Mattawa, and down to Tri-Cities). To date, we have analyzed the data from 116 AWN stations and the site-specific NOAA forecast, and only three stations showed obvious differences in the regressions from year to year using degree-days for codling moth or peach twig borer. We can also quantify the differences by looking at the total DD accumulation at the middle of September at each

Fig. 2. Average error rate in days between NOAA predictions and using site-specific corrections across all eastern Washington stations for first month of egg hatch of codling moth

Fig. 1 Error in percent of total DD accumulated between NOAA and AWN data and the percentage of stations showing a given error. Dotted line is 5% error.



station and evaluating the percentage difference between NOAA predictions and the corrected predictions. Overall, we found the corrected predictions were within 5% of the total DD accumulations at all but seven locations (Carlson, Toppenish, Hatton, Badger Canyon, Hundred Circles, Moxee and East Wenatchee) (Fig. 1). In contrast, the raw NOAA predictions showed > 5% error in 64% of the stations (Fig. 1).

In terms of how far off the model predictions would be, over all the stations, the average difference in days between NOAA (raw) predictions and the AWN data was 4.39 ± 0.1, and the average difference using the corrected data was 1.58± 0.04. The error rate for the first moth (biofix) was high for either method, although the corrected data did bring the error rate down nearly two days. The error rate for egg hatch using the uncorrected NOAA data rose continually throughout the season, while it remained fairly flat throughout the year using corrected data (Fig. 2).

The analysis of the Wilbur-Ellis (WE) data is similar to that from AWN. We had a total 49 stations from their network; but one station had what appears to be an equipment failure with only 48 data points all year, and another three showing what appears to be large deviations from the expected linear trend. Those three stations may be the result of poor sensor calibration, but will require more investigation to find out when they were last serviced. Over all but the 4 problem stations, the mean deviation in days between the NOAA raw data and the WE station averaged 5.3 ± 0.3, with the corrected data showing a variation of 1.4 ± 0.1 d in model timing from the WE stations. As with the AWN-NOAA pairing, the errors steadily increased throughout the season using the raw NOAA data, but we saw the same relatively flat error rate (≈ 1 day) all season long in the corrected data.

Objective 2 - Comparison of DD accumulations between AWN and orchard interior. Similarly to the AWN-NOAA comparison, DD accumulations of AWN and orchard interior data were linearly correlated, but not identical. In four of the five trial orchards, DD accumulations were on average slightly higher in the orchard interior compared to AWN. At Malaga, however, DD accumulations were lower inside the orchard compared to AWN. The average error of model predictions varied between sites with the smallest difference in Malaga (1.3 ± 1.6 d) and the highest in N Cashmere (4.6 ± 1.6 d) (Table 1). The maximum error in model predictions (i.e., across all models), was the similar at all sites (6-7 days), although maximum error was observed with different models (Table 1).

Looking at individual model accuracy over all stations, model predictions deviated, on average, 1.3 days (PLR) to 3.3 days (CM and PTB) between AWN and the orchard interior (Table 2). The maximum deviation was 7 days for CM, OBLR, and PTB.
These differences accumulated mainly towards the later part of the season.

Table 1. Mean absolute deviation (± SD) and maximum difference (in days) between model predictions using AWN data and temperature data from the orchard interior. Mean differences are averaged over all 7 models for each station.

Station	Mean D(d)	Max (d)	Model with max (d)
Malaga	1.3 ± 1.6	7	*Lacanobia*
N Cashmere	4.6 ± 1.6	7	CM/ OBLR/ PTB
Quincy	1.9 ± 1.3	6	OBLR
WSU Sunrise	1.9 ± 1.5	7	PTB
WSU TFREC	2.2 ± 1.4	6	CM/ PTB

Table 2. Mean absolute deviation (± SD) and maximum difference (in days) between model predictions using AWN data and temperature data from the orchard interior. Mean differences are averaged over all 5 stations for each model.

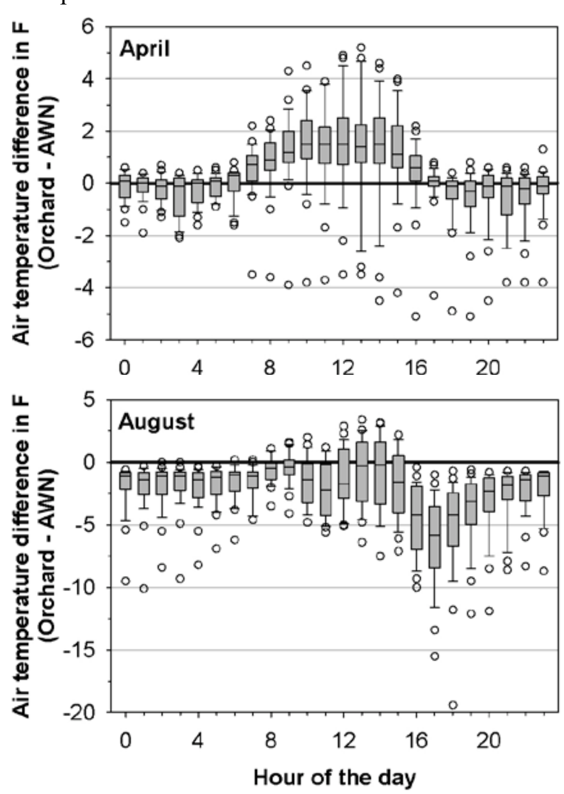
Model	Model parameter	Mean (d)	Max (d)
Apple maggot	% adult flight	1.9 ± 1.3	5
Codling moth	first moth + % egg hatch	3.3 ± 1.9	7
Lacanobia	% egg hatch	2.7 ± 1.7	6
Oblique-banded leafroller	% 4th instar	2.4 ± 2.1	7
Pandemis leafroller	% 4th instar	1.3 ± 1.5	6
Peach twig borer	% egg hatch	3.3 ± 2.1	7
Western cherry fruit fly	% adult emergence	2.0 ± 1.4	5

Although insect models only use daily maximum and minimum air temperatures, we also looked in more detail at diurnal patterns of air temperature differences and compared other environmental parameters.

Air temperature: Overall, the average difference in air temperature between orchard interior and AWN ranged between 0.5 ± 1.0 and averaged -1.6 ± 2.7°F (Table 3). However, we observed large day-to-day variations. Our initial analysis indicates that the difference in air temperature between the tree canopy and AWN exhibits a diurnal pattern that may be related to (in part) the type of irrigation. In the two orchards with overhead irrigation (Malaga and Sunrise), air temperature was higher inside the orchard during the day from April to June, but close to or lower than AWN during the night (Fig. 3). In July and August, average air temperatures within the orchard stayed below AWN values throughout the day (Fig. 3) resulting in the negative difference shown in Tables 3 and 4. The remaining three sites, which have under-tree irrigation, showed smaller differences and less variation throughout the season.

Bark temperature: Similar to our previous studies, our data showed that bark temperatures differed from AWN air temperature and that these differences changed during the season. During February through April, bark temperature was markedly higher than AWN air temperature (Table 4). We recorded temperature differences of up to 32.8 and 28.6°F at Sunrise in February and March, respectively (Fig. 4). During June through August, on the other hand, the average bark temperature was lower compared to AWN air temperature Table 4) with a few exceptions in the early morning hours (0:00-6:00) in N Cashmere, TFREC, and Sunrise (Fig. 4). May appeared to be the month of transition when bark temperatures began to drop below air temperature. This pattern in bark temperature is caused by solar radiation and the change in foliage. In spring, when the foliage is not fully developed yet, bark temperature rises above air temperature due to solar radiation. Later in summer, bark temperatures are below air temperature due to shading. More detailed analysis will show if and how irrigation affects bark temperatures. Elevated bark temperatures can affect insects that live or overwinter under bark, for example codling moth pupation and emergence in spring.

Fig. 3. Difference in air temperature between the orchard interior and AWN at Sunrise averaged for April and August 2010. Values above 0 (bold line) indicate warmer temperatures, values below 0 indicate lower temperatures within the orchard compared to AWN.



Relative humidity: Our data show that, in general, relative humidity (RH) was higher inside the orchard compared to outside, i.e. measured by AWN (Table 3, 4). The higher RH in the orchard interior is due to irrigation and tree evapotranspiration. Increased RH was more pronounced at the two sites with overhead irrigation, Malaga and Sunrise (Table 3). At the Quincy and N Cashmere site, mean RH values inside the orchard dropped below AWN data during the night hours in June, July, and August. It is not clear whether the canal adjacent to the Quincy AWN station caused higher RH at night.

Solar radiation: The average difference of solar radiation between orchard interior and AWN varied between sites ranging from 0.7 ± 5.9% to -3.7 ± 9.5% of the daily maximum radiation intensity recorded by AWN. The smallest errors were found at Sunrise and TFREC (Table 3), where the sensors were installed (already in 2009) at the edge of the orchard so that the space around the sensors was clear. The radiation

Fig. 4. Difference between bark temperatures in the orchard interior and AWN air temperatures at Sunrise averaged for March and July 2010. Values above 0 (bold line) indicate warmer bark temperatures, values below 0 indicate lower bark temperatures compared to AWN air temperature.

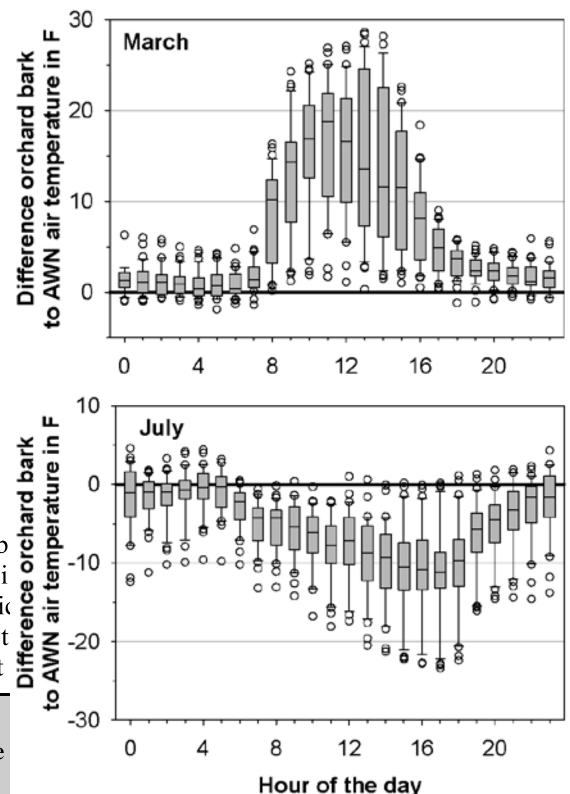


Table 3. Mean (± SD) difference of environmental parameters b
averaged over the entire season. The difference in leaf wetness i
or leaf wetness 6 April - 15 June 2010. Positive differences indic
indicate lower values in the orchard compared to AWN. *Bark t
from January - August 2010. All other data from April - August

Site	Distance (m)	Elevation difference (m)	Air Dtemperature (F)	te			
Malaga[a]	120	4	-1.6 ± 2.7	-2.6 ± 6.3	8.0 ± 6.2	-31.6 ± 80.6	65.50
N Cashmere[b]	40	0	0.5 ± 1.0	1.2 ± 4.6	0.6 ± 2.5	-16.1 ± 38.7	23.25
Quincy[b]	75	0	-0.0 ± 2.2	-0.6 ± 5.6	0.4 ± 6.5	-11.6 ± 94.4	165.00
WSU Sunrise[a]	436	0	-1.2 ± 2.6	0.2 ± 6.0*	6.8 ± 7.4	-7.9 ± 33.6	96.75
WSU TFREC[b]	39	0	-0.2 ± 1.9	0.7 ± 4.6*	3.8 ± 3.4	5.8 ± 48.4	-18.50

[a] overhead irrigation; [b] micro-sprinklers under canopy.

sensors at the other three sites, however, were installed in spring right above the canopy. It is possible that growing branches have caused some shading and resulted in negative radiation differences. We occasionally observed large negative (up to -728 W/m² or 85% at Malaga on 22 August 2010 at 1 pm) as well as positive deviations (up to 621 W/m² or 70% at Quincy on 20 May 2010 at 11 am) in solar radiation at all of our sites, in particular in Malaga and Quincy. Shading from vegetation, partial cloud cover, or topography might have caused the observed differences.

Leaf wetness: The difference in cumulative hours of leaf wetness between orchard interior and AWN varied greatly between sites and between months (Table 3, 4). At all sites, except TFREC, more leaf wetness hours were accumulated inside the orchard. Reasons for that could be that the sensors dried up

Table 4. Mean (± SD) difference of environmental parameters between orchard interior and AWN per month averaged over all 5 sites. *Bark temperature for January-March includes data from TFREC and Sunrise only.

Month	Air Dtemperature (F)	Bark temperature (F)*	Relative humidity (%)	Solar radiation (W/m^2)D(% difference)	Hours leaf wetness
January	-	-0.2 ± 3.3	-	-	-
February	-	1.8 ± 5.4	-	-	-
March	-	4.9 ± 6.1	-	-	-
April	0.3 ± 1.3	4.0 ± 4.3	1.5 ± 3.7	-7.8 ± 57.9 (-1.0 ± 7.9%)	19.1 ± 19.2
May	-0.0 ± 1.7	1.2 ± 3.8	3.6 ± 5.3	-9.2 ± 64.7 (-1.1 ± 8.0%)	37.3 ± 41.5
June	-0.2 ± 1.7	-0.8 ± 3.7	3.7 ± 5.3	-11.3 ± 64.1 (-1.2 ± 7.4%)	38.8 ± 56.6
July	-1.2 ± 3.0	-4.3 ± 5.8	5.0 ± 7.8	-15.3 ± 59.7 (-1.7 ± 6.6%)	153.7 ± 228.4
August	-1.3 ± 2.8	-2.8 ± 5.2	5.3 ± 7.6	-23.1 ± 84.4 (-2.7 ± 10.1%)	223.0 ± 268.3

more slowly due to higher RH or irrigation that wetted the sensors, particularly in the summer months. Furthermore, sensor calibration, i.e. setting the dry/wet transition value correctly, is crucial and varies between sensor types. The wet threshold for AWN sensors is 0.3. After comparing leaf wetness, RH, and dew point, we set the threshold for our sensors 15%. Underestimating leaf wetness could result in a false negative prediction of fireblight infection. Fireblight infections occur from rain, dew, or misting from irrigation of about two hours.

Objective 3. No direct progress on this objective. The weather equipment has been received, and we are in the process of locating orchards for this objective. The original plan was to find high-density orchards with overhead sprinklers that we can turn off in a section of the orchard. The problem with this setup, however, is that the overhead sprinklers function as irrigation which would have to be replaced in some way, which would be costly and time-consuming. Alternatively, we are now looking for pairs of very similar high-density orchards in close proximity to each other - one orchard with overhead irrigation and the other one with under-tree irrigation. Setup of the weather stations will begin during the next few months, and data collection will start in 2011.

CONTINUING PROJECT REPORT **YEAR**: 2 (2011)
WTFRC Project Number: TR-09-909

Project Title: Dense distributed environmental sensing via wireless sensor networks

PI: George Kantor
Organization: Sensible Machines, Inc.
Telephone/email: 412-867-8665/george.a.kantor@gmail.com
Address: 100 Boundary St.
City: Pittsburgh
State/Zip: PA/15207

Cooperators: Jim McFerson (WTFRC), Jay Brunner (WSU-Wenatchee)

Total Project Request: **Year 1:** $25,000 **Year 2:** $10,000

Other funding sources:

Agency Name: USDA Specialty Crops Research Initiative
Amt. requested/awarded: $5.4M (plus $5.5M non-federal match)
Notes: As faculty at the Carnegie Mellon University Robotics Institute, Dr. Kantor is a Co-Project Director on the project titled *Precision Irrigation and Nutrient Management for Nursery, Greenhouse and Green Roof Systems: Wireless Sensor Networks for Feedback and Feedforward Control (PINM)*. This project will further develop and apply the CMU sensor network for distributed sensing and irrigation control in horticultural environments (greenhouse, nursery, and green roof). This project has been funded for five years, beginning October 2009.

Agency Name: USDA Specialty Crops Research Initiative
Amt. requested/awarded: $6.1M (plus $6.1M non-federal match)
Notes: Dr. Kantor is also Co-Project Director on the project titled *Comprehensive Automation for Specialty Crops (CASC)*. CASC has a broad charter to investigate and develop automation technologies for specialty crops, with a specific focus on the apple industry. Much of the CASC work is being done in Washington orchards providing Dr. Kantor with resources that can be leveraged to partially support the anticipated travel requirements of this proposal to WTFRC. CASC is a fully funded four-year project that began in October 2008.

WTFRC Collaborative expenses:

Item	**9/1/2009-9/1/2010**	**9/1/2010-9/1/2011**
Stemilt RCA room rental		
Crew labor	$3,120	$3,120
Shipping		
Supplies		
Travel		
Miscellaneous		
Total	$3,120	$3,120

Budget 1
Organization Name: Sensible Machines, Inc. **Contract Administrator:** Stephan Roth
Telephone: 412-398-2694 **Email address:** sroth@sensiblemachines.com

Item	**9/1/2009-9/1/2010**	**9/1/2010-9/1/2011**
Salaries	$5,000	$2,000
Benefits		
Wages		
Benefits		
Equipment		$5,500
Supplies	$500	
Travel	$3,500	$2,500
Miscellaneous		
Total	$25,000	**$10,000**

Footnotes:

Objectives

The overall objective of this project is to prove the viability of distributed wireless sensing for use in orchards. Year 1 activities established a 10-node network at Sunrise orchard with temperature and relative humidity being measures at 3 elevations (1m, 2m, and 3m) at 10 sites distributed over the orchard. This network come online in February 2010 and has been collecting data almost continuously since the (see objective XXX below).

The primary objective of Year 2 is to maintain this network and begin using the incoming information for science and management activities. Specific objectives are:

1. Build a dedicated shed and install a stable power supply for the sensor network basestation at Sunrise orchard.
2. Expand the sensing capabilities of the Sunrise network to include soil moisture, light, and wind speed/direction measurements.
3. Reconfigure the existing network to better suit the needs of ongoing scientific research at Sunrise.
4. Establish a small test network at a commercial site and use it to inform water management.

Significant Findings

The sensor network installed at Sunrise in Year 1 was a commercially available system provided by Decagon Devices. It has performed well over the course of the past 8 months, withstanding extreme heat (~105F) and cold (~0F). It has required almost no except for changing the batteries. The nodes take 5 AA Alkaline batteries, which have lasted an average of 6 months at a data rate of one set of measurements every 5 minutes. Real-time cellular access to the data has been reliable, with the exception of problems due to Sunrise power issues described below. Real-time data is available online at:

http://sensorweb.frc.ri.cmu.edu:3404/

(username: guest, password: guest).

The only real problem with the system has been the reliability of the power at the Sunrise orchard. The sensornet basestation is currently housed in a shed that is shared by the Sunrise staff. This shed is powered by a single circuit, which is overloaded. As a result, the circuit breaker trips frequently, causing the basestation to shutdown. When the basestation is shut down, data is still logged, however it is not remotely available. When power returns, the basestation comes back up automatically, however there is a gap in the remotely available data log spanning the period that power was down. This problem was first noticed in July of 2010, during which it occurred approximately once per week. Since then it has worsened and, as of October 2010, power outages occur 3-4 times per week. Implementing a permanent solution to this problem is our highest-priority objective for Year 2 activities.

Methods

Objective 1 (fix Sunrise Power): We will purchase a used 8' by 10' shed and install it at Sunrise orchard. The shed will be placed near a dedicated circuit for this project, providing reliable power. The budget for purchasing the shed is $1,500. Labor to set up the shed and install the basestation is covered by PI salary and WTFRC crew labor.

Objective 2 (expand sensing capabilities): Sensors will be purchased to be added to free channels on the nodes on the existing Sunrise network. A total of $2,400 has been budgeted to purchase 10 soil moisture/temp sensors, 5 soil matric potential sensors, 3 wind speed/direction sensors, and 3 photosynthetically active radiaion (PAR) sensors. These sensors will be purchased and installed by the PI prior to the 2011 growing season.

Objective 3 (better meet science needs): The PI will work with Jay Brunner to reconfigure the existing Sunrise network to support of a studies being conducted in fixed pesticide/water delivery systems, fruit sunburn protection, and insect pest and disease modeling. In addition the adding the new sensors described in Objective 2, this will include moving some of the existing equipment at Sunrise to more relevant locations. The installation will be done by the PI prior to the 2011 growing season.

Objective 4 (investigate water managent): A small pilot network consisting of Decagon's new cellular-enabled sensor network system will be installed at a commercial site and used to inform water management. In particular, we will install a 2-node system equipped with soil moisture content and soil matric potential sensors placed at 3 depths (20cm, 60cm, 100cm). The resulting data will be available in real time. It will be shared with the irrigation manager at the orchard. We will provide assistance in interpreting the data and compare it with other means of collecting soil moisture data being used at that site. We have budgeted $1,600 to purchase the nodes and sensors required for this effort, which Decagon will augment with and additional $1,600 equipment match. In addition, Decagon will provide labor to assist with system installation. This installation work will be done by the PI and personnel from Decagon prior to the 2011 growing season.

Results

The system is in place at Sunrise and continues to perform as expected. A detailed description of the current set-up as well as documentation on how to obtain and interpret the data is contained in the March 2010 continuing report for this project.

CONTINUING PROJECT REPORT **YEAR**: 2010
WTFRC Project Number:

Project Title: Intelligent bin-dog system for tree fruit production

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Cooperators: WA Producers

Total project funding request: **Year 1:** 98,397 **Year 2:** 98,654 **Year 3:** 102,040

Budget 1
Organization Name: WA State University **Contract Administrator:** M.L. Bricker
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Item	**2010**		
Salaries			
Benefits			
Wages			
Benefits			
Equipment			
Supplies			
Travel (Zhang)			
Travel (Lewis)			
Publications			
Miscellaneous			
Total[1]	10,000		

Footnotes: [1] A reduced budget of $10,000 was proved for Yr 2010 to support a preliminary study.

INTRODUCTION

This project was proposed to develop a smart "bin-dog" system, through creating the key capabilities of (1) recognizing the human picker, namely the "master"; (2) understanding the master's actions in picking process; and (3) appropriately responding to the master's actions to place the bin at an optimal position for achieving a high overall productivity. While this device will first be designed to work in typical Washington apple and cherry orchards, it should be usable in all tree fruit orchards with none or some very limited minor modifications. The core technology of this smart "bin-dog" system can further be used as one constructing piece to the core technology for robotic orchard machinery to support higher level of automated tree fruit production. WTFRC has requested the project team to carry out a preliminary study on developing more illustrative concept of this smart bin-dog system before conducting the full scale research. A reduced budget of $10,000 was proved for year one (2010) to support this preliminary study. This continuing report summarizes the revised objectives and research plans, as well as the up-to-date progresses achieved in the past report period.

REVISED OBJECTIVES

As the primary goals of originally proposed research were to develop the core technologies for building a smart "bin-dog" and integrate the developed technologies on autonomous "bin-dogs" implementable in tree fruit orchards, the revised research objective is to perform an illustrative concept development using manned machinery in performing proposed smart bin-dog operation in commercial orchards to verify practicability and productivity in comparing with typical manual harvest process. To accomplish this revised goal, this project will be conducted in both field test and data analysis phases as specified below:

(1) Select a proper bin carrier driven by a human operator to mimic the proposed smart "bin-dog" in demonstrating the conceptual functions of real-time master recognition, tracking and following, test the effectiveness of this proposed method in comparing with conventional distributed bins method in commercial orchards.

(2) Analyze the performance data of operations collected from both the mimicked "bin-dog" operation and the conventional operation in a comparable situation, and prepare the evaluation documents.

(3) Develop the conceptual technology of autonomous "bin-dog" by modifying a Deere Gator utility vehicle, and demonstrate it in orchard environment.

These concept-approval objectives will be accomplished during the 2010 harvest season. The deliverables of this preliminary project will include (i) a demonstration test and result comparison report, and (ii) a revised full scale phase II research proposal.

METHODS

As described in the "objectives" section, this revised project of preliminary study was to demonstrate the concept of smart "bin-dogs" and compare its effectiveness with conventional harvest process. By this approach a movable bin carrier will be driven by a human operator to follow two pickers by placing the bin within their job vicinity to reduce the unproductive time in fruit picking. A conventional operation will be planned in an adjacent row during the operation. The pickers will be switched after complete a row of picking to minimize the efficiency caused by individual pickers in harvesting the second row of the fruits.

Defining the conceptual process is the essential step for this preliminary research. In this project, the ideal demand is a "slave" bin carrier which can move a fruit bin following a human picker, and position the bin at a convenient location near the picker to maximize the picker's productive time during fruit harvest. We will use a human-driven bin carrier to test if this conceptual system could actually achieve the goal of reducing labor demand at harvest through improving work efficiency. We have planned to conduct the test runs of the conceptual process at a cherry orchard and an apple orchard, and use the overall picking efficiency as the base to analyze effectiveness of using the conceptual technology. It is worthy to point out that the defined ideal demands at this stage may or may not be necessary the final workable solutions for solving the labor demand and supply challenge, but provide a start point to search for practical solutions for solving the problem.

The **practicability assessment** is the first attempt in this preliminary research. To simplify the concept demonstration process by focusing only on solving the critical issues one at a time, the practicability assessment work will be performed based on a research mobile platform based on an existing bin carrying platform driven by a human operator. In this test, the operator will perform all designated "bin-dog" functions, from "master" detecting and tracking, finding an optimal path to safely following the picker(s), and precisely positioning the bin at a convenient location in the vicinity of the picker without interfering with his/her performance to maximizing productive motions of the picker. As a critical concept-approval step of addressing the practicability questions before it being actually developed, a comparison test as described before will be conducted in parallel to the "bin-dog" supported operation in adjacent rows. Evaluation documents will be prepared based on the results obtained from actual scale field demonstration tests

Proposed Schedule and Up-to-Date Accomplishment: Table 1 summarizes the revised project management plan and the up-to-date accomplishment for the revised preliminary study.

Table 1. Project Management Plan, Expected Outcomes and Up-to-Date Accomplishments

No.	Milestone	Time Period	Deliverables	Accomplishments
1	Define a conceptual "bin-dog" using a manned-vehicle	1Q-2Q, 2010	Basic requirements for an intelligent fruit bin carrier workable in orchards	A conceptual process of using manned bin carrier is under development
2	Design conceptual approval field tests in a cherry orchard	2Q-3Q, 2010	Perform run-one test in a cherry orchard and build a demo "bin-dog"	Completed run-one concept-approval test and made a few necessary modifications.
3	demonstration tests & documentation	3Q-4Q, 2010	Complete concept-approval test report and a full scale research proposal	Demonstration tests in apple orchard planned.

Results Obtained from Preliminary Tests in Cherry Harvest: As planned, the first run demonstration test of the conceptual "bin-dog" system was tested in a cherry orchard during the cherry harvest in July 2010. In this test, a tractor equipped with a front-mount forklift was used as the "testing bin-dog". The main purposes of this preliminary test were to:

1. Validate the practicability of the conceptual "bin-dog" in commercial tree fruit orchards; and
2. Compare the overall efficiencies of a "bin-dog" and the conventional "pre-distributed bins" in a typical harvest operation.

The first run demonstration test was successfully conducted, but the results were imperfect, attribute to the fact that the selected "bin-dog" platform, an orchard tractor with a front-mount forklift to carry the bin, was too large that it could not get into the corridor between two rows of trees. Therefore, this demonstration test was conducted under such a situation that the operation using the "bin-dog" platform was conducted at the edge row of the trees (namely the most out row of the orchard), and the pickers were picking fruits from only one row. Whereas, the comparison test was conducted in inner rows, the pickers were picking fruits from two rows on each side of the bin corridor. As illustrated in Fig. 1, the surface data on bin-filling time in "bin-dog" support operation did not shown an obvious improvement over the conventional operation. If considering the picking supported by the "bin-dog" was at the most outside row of an orchard, and the comparing operation was performed in an inner row, such

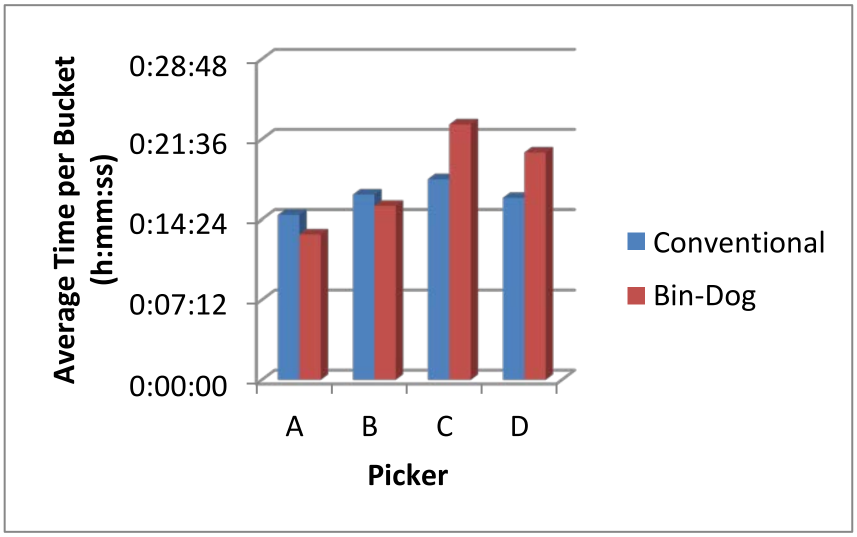

Fig. 1. Average bin filling time for four pickers under either the conventional or the "bin-dog" supported operations in cherry harvest.

results have proved that the "bin-dog" support operation will at least be comparable to conventional operation. A more comparable test will be conducted by selecting a platform could easily travel in between the tree rows, as the human operators could, to conduct a fairer comparing test under similar operating condition in apple orchard this Fall.

Planned Second Validation Test in Apple Harvest: A second validation test has be planned by using a human-powered simple bin moving platform to make the "bin-dog" demonstration tool travelable in any inner rows of an orchard. The second validation test, designed as the first test, will be conducted in an apple orchard in 2010 harvest season. Both the "bin-dog" and the conventional overall harvest efficiency data will be collected and compared, and the significance of difference, if there is one, will be analyzed to confirm the result.

Development of an Autonomous Picker Tracking and Following System: To support the full scale research of the smart "bin-dog" system, we have also started the development of an autonomous vehicle platform to demonstrate the picker tracking and following capability. The experimental platform was developed based on a John Deere Gator TE electric utility vehicle, by using existing components due to the limit on resources. To-date, this platform has been equipped with GPS-based automatic driving function, and visual picker detecting and tracking functions. We are current investigating a few computer vision technologies, such as stereo camera, laser scanner, and sonar, to assess their applicability on the platform in finding pickers and tracking them.

Fruit Weighing Capability: During the first run of the preliminary field tests, we have learned a challenging issue which bothered many growers: how to effectively monitoring individual picker's productivity and overall yield monitoring during fruit picking. We have been inquired the possibility of providing fruit weighing and recording capability to the "bin-dog". We were told that it could help growers to recover the costs even in the first year of adopting such a "bin-dog" if it could accurately and reliably weigh and track actual yield.

This preliminary investigation is expected to be completed this year. A complete report, along with a revised full-scale proposal, will be presented in the next review meeting.

CONTINUING PROJECT REPORT **YEAR**: 3 of 3
WTFRC Project Number: TR-07-706

Project Title: Mechanized blossom and green fruit thinning

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Cooperators: Tory Schmidt and WTFRC internal program, PA Growers, WA Growers, Steve Miller, USDA-ARS; Craig Hornblow, New Zealand First, Michael Blanke, University of Bonn

Total Project Request: **Year 1:** 17,172 **Year 2:** 18,304 **Year 3:** 18,762

Other funding sources

Agency Name: USDA NIFA – SCRI - Innovative Technologies for Thinning of Fruit
Amt. requested/awarded: 1 M / 1 M
Notes: Penn State - Schupp / Baugher awarded 180,000K
WSU – Lewis / Pitts awarded 133,000K

Agency Name: PA Peach and Nectarine Board
Amt. requested/awarded:

WTFRC Collaborative expenses:

Item	2008	2009	2010
Wages	5,000	5,250	5,500
Travel	3,000	3,250	3,500
Total	8,000	8,500	9,000

Budget 1

Organization Name: Penn State University **Contract Administrator:** Timothy Stodart

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Item	2008	2009	2010
Salaries	6,387	6,611	6,842
Benefits	1,648	1,706	1,765
Wages	3,840	3,840	3,840
Benefits	315	315	315
Equipment	0	0	0
Supplies	1,000	1,000	1,000
Travel	0	0	0
Total	13,190	13,472	13,762

Footnotes: Estimated salary costs are based on current salary rates (fiscal year 2007-08) escalated approximately 3.5% beginning July 1 of each subsequent year. University policy has been to award salary increases on the basis of merit only.

Fringe Benefits: Rates are computed using the rates of 25.8% applicable to Category I salaries; 15.7% applicable to Category II graduate assistants; 8.2% applicable to Category III non-student wages and fixed-term II salaries; and 0.4% applicable to Category IV student wages for the current fiscal year of July 1, 2007 through June 30, 2008. If this proposal is funded, the rates quoted above shall, at the time of funding, be subject to adjustment for any period subsequent to June 30, 2008 if superseding Government approved rates have been established. The fringe benefit rates are negotiated and approved by the Office of Naval Research, Penn State's cognizant federal agency.

Budget 2

Organization Name: WA State Univ. **Contract Administrator:** MaryLou Bricker

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Item	2008	2009	2010
Salaries	0	0	0
Benefits	0	0	0
Wages	1,700	0	0
Benefits	282	0	0
Equipment	0	0	0
Supplies	500	2,000	1,500
Travel	1,500	2,832	3,500
Total	3,982	4,832	5,000

Objectives:

1. To evaluate the effect of timing on efficacy of mechanical blossom thinning, relative to peach / nectarine and apple bloom stages.
2. To evaluate several labor-efficient thinning methods in various combinations.
3. To evaluate the effect of pruning strategies to influence hanger orientation on peach cropload and on the efficacy of the Darwin vertical string thinner.
4. To compare the efficacy of a prototype horizontal mechanical blossom thinner or a rope thinner in traditional vase shaped peach canopies, relative to hand thinning
5. To evaluate the effect of Darwin string thinner in apple varieties and systems
6. To evaluate the Uni Bonn string thinner in apples and cherries
7. Establish best management practices for string thinners.

Significant Findings:

2010 Significant Findings: PA

- Operating the Darwin string thinner with new hydraulic controls in perpendicular V peach trees provided thinning equal to (in White Lady), or better (in Saturn) than that provided by standard positioning by tractor.
- Baseline data was obtained with sonar and with laser sensors for adapting the Darwin thinner to autonomous operation.
- String pattern on the Darwin spindle does not appear to be an important parameter for thinning of stone fruit.
- Peach fruit removal was about the same regardless of the cycles per minute at which the USDA Drum Shaker was operated.
- Peach and nectarine tree damage from the USDA Drum Shaker was minor in 2010, and there was no clear trend in damage incidence from increasing the cycles per minute.
- Spur leaf and flower removal of Pink Lady apple trees was excessive when the Darwin string thinner was operated with four string columns (360 strings) or six columns (540 strings).
- Increased Darwin spindle speed resulted in a linear increase in Gala apple flower cluster removal
- As Darwin spindle speed increased there was a decrease in apple leaf area per spur, which became excessive at 240 rpm or above.
- Darwin spindle speed had an inverse relationship with Gala apple fruit set, which became dramatic at 240 rpm and higher.
- Increased Darwin spindle speed resulted in a higher incidence of an observed 2nd flush of bloom, increasing the duration of Gala apple tree susceptibility to fire blight infection.

2010 Significant Findings: WA

- Darwin string pattern did not significantly impact bloom removal or final fruit set in either Grand Bright or Washington Pride nectarine.
- Nectarine final fruit size and weight was greater in Darwin thinned treatments over hand blossom thinned treatments. Bloom thinning with the WA Helix string arrangement on the Darwin resulted in larger fruit when compared to the standard string arrangement and hand blossom thinned control.
- Gold Bar apricot thinned with the Darwin responded with a slightly larger fruit size and weight when compared to hand blossom (raked) thinned trees.
- There was no significant difference in the amount of bloom removed or final fruit set between the Darwin thinned and hand bloom thinned (raked) in Robada trial.

- Gold Bar and Robada apricot trained to angled trellis respond positively to Darwin thinning.
- No remarkable fruit or wood damage was recorded in Darwin thinned stone fruit trials.
- Across 4 Darwin trials in 4 apple varieties, the higher the spindle rpm the greater the thinning and the greater percentage of doubles, triples and quads left intact.
- Across 4 Darwin trials in 4 apple varieties, the range of king bloom survival in Darwin thinned treatments was 60-84% and king bloom survival was not dependent on spindle rpm's.
- The Bonner string thinner has potential as a mechanical thinner in WA.
- The Bonner thinner in Granny Smith at 3 different speeds was effective reducing bloom by breaking down clusters to singles or removing clusters completely.

Methods: PA

Testing of the string thinners and the drum shaker were continued through the 2010 growing season. Modifications to both units were made. Sensors were added to the string thinner to test the feasibility of automatic positioning of the spindle in perpendicular V peach orchards, which would reduce driver fatigue and potentially increase the speed of thinning. Penn State Ag Engineering MS candidate Reuben Dise investigated sonar and laser sensors for this purpose, in cooperation with scientists from Carnegie Mellon.

Dise also installed and tested hydraulic controls for positioning the spindle. Initial tests were made to compare positioning of the spindle by manipulating the new controls with a joystick versus the standard tractor positioning method. These spindle positioning controls were compared in young Saturn and White Lady peach trees trained to the perpendicular V system.

Darwin thinner spindle string pattern was evaluated to compare the "standard" 2 string column arrangement to 3- and 6-column helix patterns, all utilizing 90 total strings. Trials were conducted in both perpendicular V- and open center vase- trained peach trees. A helix string arrangement that brought the next distal string into contact with the tree canopy, "helix up" was compared to a string arrangement that brought each succeeding proximal string into contact, which we labeled "helix down".

Testing continued to see if altering the oscillating drum speed between 300 and 400 cycles per minute of the USDA Drum Shaker affected green peach fruit thinning efficacy or incidence of peach limb damage. These treatments were compared to a hand thinned control in young PF 17 peach and Fantasia nectarine trees which were trained to the perpendicular V system. The forward speed of the drum shaker vehicle was 4.0 km per hour (2.5 mph), and treatments were applied at 35 days after full bloom.

Pink Lady apple trees were thinned with the Darwin string thinner at bloom, with three different sting densities. Gala apple trees were string thinned at five spindle rotation speeds and compared to an untreated control to determine the appropriate severity level to achieve adequate thing with minimal tree/ leaf damage. The tractor speed was 3.0 mph and the spindle speed varied from 180-300 rpm, with 30 rpm increments. Conducted by MS candidate Tom Kon, flower and spur leaf removal, fruit set, yield, fruit size distribution and fruit quality were evaluated.

Results and Discussion:PA

Baseline data was obtained with sonar and with laser sensors for adapting the Darwin thinner to autonomous operation. This data is currently being analyzed to determine if the automated system will be able to accurately sense the trees and position itself and will match the performance of the manually operated machine.

Operating the Darwin thinner with the new hydraulic controls and joystick in perpendicular V peach trees provided thinning equal to (in White Lady), or better (in Saturn) than that provided by standard positioning by tractor. Rotation of the Darwin spindle requires a continuous flow of oil from the hydraulic system, which reduces flow to other hydraulic control systems. Thus in order to operate the additional hydraulics required by the joystick control method, it appears that a separate hydraulic system will have to be employed, similar to findings in SC.

All string patterns we tested on the Darwin thinner provided similar amounts of flower removal and fruit set in peach in two of three trials. In one trial the treatment “helix up” removed significantly more flowers than the other string patterns, but slow motion photography confirmed visual observation that flowering shoots were being contacted by strings repeatedly with all the string patterns, making it unlikely that string pattern would influence thinning or the pattern of flower distribution. Frequency distribution graphs revealed that all string patterns were equally effective in reducing the numbers of flowers and setting fruits per shoot. String pattern on the Darwin spindle does not appear to be an important parameter for thinning of stone fruit.

Peach fruit removal was about the same regardless of the cycles per minute at which the USDA Drum Shaker was operated. Peach and nectarine tree damage from the USDA Drum Shaker was minor in 2010, and there was no clear trend in damage incidence from increasing the cycles per minute. These results differ from earlier work, possibly in part because the trees used for this year’s study were younger 4th leaf trees, and had been trained and pruned to more closely adhere to the perpendicular V training system than trees used in earlier trials. Thus the diameters of the scaffolds were smaller than those of trees in earlier trials, and less rigid. Also, there was little or no secondary limb structure in which the nylon rods could become entangled. The drum shaker thins by shaking the scaffolds, thus the size and branch hierarchy of the tree canopy will be an important cofactor in thinning and tree damage resulting from this treatment.

Spur leaf and flower removal of Pink Lady apple trees was excessive when the Darwin PT 250 was operated at 240 rpm with four string columns (360 strings) or six columns (540 strings). A helix pattern of 90 strings, which is the equivalent of two full columns of 9-string panels, did not remove excessive amounts of flowers and the thinning severity with this pattern was deemed appropriate. This pattern was selected for the following apple severity trial.

Increased thinning severity, as affected by increasing spindle rotation speed, resulted in a linear increase in Gala apple flower cluster removal. As thinning severity increased there was a decrease in leaf area per spur, which became excessive at 240 rpm or above. Thinning severity had an inverse relationship with fruit set, which became dramatic at 240 rpm and higher. Increased thinning severity resulted in a higher incidence of an observed second flush of bloom, increasing the duration of susceptibility to fire blight. From these preliminary findings we conclude that recommended operation parameters developed in Germany result in excessive damage and fruit set reductions under Mid-Atlantic U.S. conditions. Forward tractor speed was 3 mph (4.8 km/hr), at the lowest end of German-recommended speeds, which may in part explain the greater severity we documented. More research will be needed to adapt this technology to our growing conditions. Yield, fruit size distribution and fruit quality are currently being evaluated.

Methods: WA

Stone Fruit

We established 4 replicated stone fruit Darwin trials in 2010. Taking previous results and grower identified goals, we established 2 apricot trials that compared Darwin bloom thinning to hand bloom/rake thinning – using the single string arrangement (standard) and single speed (237 rpm). We established 2 nectarine trials that evaluated Darwin WA Helix string arrangement, Darwin standard string arrangement and hand bloom thinning.

Apple

We established 4 replicated Darwin trials and 1 replicated Bonner apple trial in 2010. Darwin trials included Fuji and Honeycrisp at 280 and 320 rpm; Golden Delicious at 220, 240 and 260 and Granny Smith at 200, 220 and 240 rpm. Untreated controls varied across blocks depending on grower practices.

Darwin trials were conducted at open king, side balloon stage. King bloom survival and incidence of fruit/ wood damage were recorded.

Cherry

We established 2 replicated trials in sweet cherry trained to UFO. Thinning was conducted at 80% plus bloom. Treatments included spindle speeds of 200, 220 and untreated control. Dormant thinning demonstration trials were conducted in February.

Results and Discussion

Of the 2 apricot trials, trial 1 was lost to spring frost damage. Post bloom data is not available for trial 1. With repetition we have shown that when compared to hand blossom thinning with rakes, the Darwin thinner is equally effective in removing bloom and reducing fruit set and that final fruit size is either the same or larger in Darwin thinned trees when compared to hand blossom thinned or green fruit thinned. Mechanized thinning apricots with the Darwin thinner set between 200 and 240 rpm has no negative impact on final fruit size when compared to hand blossom thinning.

Nectarine trials offered 2 opportunities to measure impact of Darwin thinning through green fruit thinning stage. Only the Grand Bright trial was used to collect final fruit size, fruit quality and yield data. All treatments were made between 70 and 90% FB. We evaluated the WA Helix cord pattern against standard alternating pattern and hand blossom thinning (no rakes). Nectarine final fruit size and weight was greater in Darwin thinned treatments over hand blossom thinned treatments. String pattern did not impact blossom removal or fruit set in the spring, but final fruit size was larger and weighed more in trees thinned with the WA Helix pattern when compared to the standard pattern.

Apple trial data is still being analyzed. Only one of the Darwin trials was impacted by frost. Data in that trial is limited to pre and post bloom counts. Using trial run immediate observations as a guide, both the Fuji and Honeycrisp trials were established using agreed upon rpm's (280-320) and speed (3mph). In both cases we overthinned the crop. In all Darwin trials, the higher the rpm the greater the thinning and the greater percentage of doubles, triples and quads left intact. This is the first year we collected data on king bloom survival – across all Darwin trials, king bloom survival ranged between 60 and 84%. Although only significant in the Granny Smith trial, in all trials, percent king bloom survival decreased with increased spindle rpm speeds. Flower composition data also indicated that rpm speed impacts the number of blanks, singles, triples and quads. The *high speed* Fuji and Honeycrisp treatments left the greatest number of flower clusters intact. Regardless of rpm speed, the Golden Delicious and Granny Smith low speed trials had almost no doubles, triples or quads left intact.

The Bonner string thinner was used in one Granny Smith trial. Data analysis is not yet complete but we are confident this thinner has potential in our systems. The Bonner at 3 different speeds was effective in reducing bloom by breaking down clusters to singles or removing clusters completely.

Bloom thinning with the Darwin in UFO cherries yielded mixed results. Across the trials and demonstrations we more often over-thinned than under-thinned. The amount of blank wood in the Darwin treated trees was considered unacceptable. Data analysis has not been completed. Dormant thinning with the Darwin removed 20-27% of flower buds (not clusters). 2010 cherry results warrant further research in sweet cherries and in specific cherry systems.

CONTINUING PROJECT REPORT **YEAR**: 2010
WTFRC Project Number:

Project Title: A portable device for rapid and accurate rating of fruit size and color

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Cooperators: Caixi Zhang, Washington State University

Total Project Request: **Year 1:** 48,396

Other funding sources: None

Budget 1
Organization Name: Washington State University **Contract Administrator:** M.L. Bricker
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Item	2010	(type additional year if relevant)	(type additional year if relevant)
Salaries[1]	19,000		
Benefits	5,396		
Wages	--		
Benefits	--		
Equipment[2]	10,000		
Supplies	6,000		
Travel (Zhang)	3,000		
Travel (Whiting)	2,000		
Travel (Wang)	1,000		
Publications	2,000		
Miscellaneous			
Total	48,396		

Footnotes: [1] 50% time of one post-doctoral research associate.
[2] An imaging system, an artificial lighting system, programming software and a computer.

OBJECTIVES

The primary goal of this research is to develop a concept of automated fruit rating in terms of fruit color and size. In this feasibility study phase, we have used cherry fruit as examples to study the feasibility of using color imaging technologies to solve the problem in a laboratory environment. To achieve this goal, four specific objectives were conducted, or still under investigation:

(1) Search and review previous attempts on developing similar technologies for fruit quality assessment, as well as for other applications. Analyze the reasons for unsuccessful attempts and determine the key attributers to successful systems.

(2) Based on outcomes obtained from objective (1), develop a prototype system to prove the feasibility of proposed concept.

(3) Verify color and size detection capability of the device and improve its detecting sensitivity, rating accuracy and reliability of the prototype system via laboratory tests. Demonstrate the developed system to growers/users in a laboratory setup.

(4) Prepare technical documents, develop a research plan for converting the conceptual research outcome into a portable fruit color and size measurement system practicably usable in orchards and/or in packing houses, and transfer the technology to proper industries and stakeholders.

Up to date, we have done research activities for objectives (1) and (2), and are working on objective (3). The whole feasibility study project will be completed by April, 2011. The deliverables of this project will include (i) a prototype device implementable in a laboratory environment for rapid and accurate rating of cherry size and color; (ii) a complete technical document; and (iii) a research plan for the second phase development to build a portable fruit color and size measurement system usable in orchards and/or in packing houses.

SIGNIFICANT PROGRESS

The significant progress accomplished in the past six months includes:

- Finished literature review on automated rating for cherry color and size;
- Developed a prototype image acquisition system for the feasibility study;
- Used computer vision to distinguish the color differences among seven levels of a standard cherry color chart in a lab environment;
- Developed a test algorithm to match the color of a cherry to a level on the color chart;
- Found factors that prevent the current system from achieving better color rating accuracy; and
- Developed a test algorithm for measuring cherry size using the same device.

METHODS

The method used in this project employed five steps in conducting the research:

1. Develop a sensing system platform for image acquisition and processing;
2. Use the platform to capture cherry images in lab environment with adjustable lighting conditions as the baseline data;
3. Develop an image processing algorithm for identifying cherry colors and classify those colors into seven levels of standard cherry colors;
4. Develop an image processing algorithm for measuring cherry size and
5. Conduct a series of validation tests to test the accuracy and robustness of developed algorithms.

Brief descriptions of those five steps of development are provided as follows:

Image Acquisition System Platform Development

The main functions of this image acquisition system were to shoot and store cherry images. This system is designed to be used in a laboratory environment, with adjustable lighting conditions to simulate outdoor lighting variations. To achieve the required functionality, the system consisted of:

1. Artificial lighting equipment: Two daylight bulbs, one with color temperature 5,400 K (9, 260 F) and the other one with 6,500 K (11,240 F), were used as the lighting sources for this research platform. The reason for such a selection was that 5,400 K is close to typical daylight color temperature (around 5,500 K), and 6,500 K is typical outdoor light color temperature in an overcast day. Those two light sources helped study how the varying outdoor lighting affects the detection the true color of cherry fruits;
2. Image acquisition equipment: A camera and a flatbed scanner were used in the platform for image acquisition. The camera (Sigma SD14 digital color camera) was used to take images of both cherry samples and the color chart under the lighting conditions created by two daylight bulbs, and the flatbed scanner (HP Scanjet 6750) was used for analyzing the color properties to support the development of the color rating algorithm; and
3. A laptop computer was used to store collected images and run image processing algorithms.

Method for Color Rating

In this study, we used the standard cherry color chart as a baseline truth for color rating. The process was to match the color of a cherry with one of the seven levels presented in the standard chart. The matched color level was treated as the color rating of the cherry sample. To perform this matching, we first used an image processing technique to quantify the seven red levels, with each level having a range of redness values. Then, the color rating algorithm detected the redness value of a cherry sample, and searched for a matched range (level). An algorithm for lighting change adaptability was developed and used to compensate for light intensity changes.

Method for Size Measurement

A two-step fruit size measurement method was developed in this study:

1. Started with the development of a cherry size measurement algorithm based on single cherry fruit image analysis; and
2. Followed by find ways to separate single cherry fruit from a multiple fruits scene, then use the single fruit sizing algorithm developed in the first step to measure cherry size.

Validation Tests

In this validation test we used a large number (>200) of cherry fruit samples to test the performance of developed algorithms. Those tests were also taken place in the laboratory environment. All fruit samples were rated in color and size manually using a standard color chart and sizer. The manually measured data were used as the baseline data to check against the device measured parameters.

RESULTS & DISCUSSION

Color Rating

We processed the baseline truth color data obtained from the flatbed scanner using the develop color processing algorithm. Results showed that the developed algorithm could effectively and accurately quantify all seven levels of redness from the standard cherry color chart. The entire range of redness was defined within a grey level range between 0 and 255; with the darker the redness was, the lower the grey level value would be. A redness boundary was found for every two adjacent rating levels, as shown in Figure 1. Those boundaries defined a redness range for each color level. For instance, if the gray level value of a red object was somewhere between 147 and 185, it could be treated as a level 3 redness.

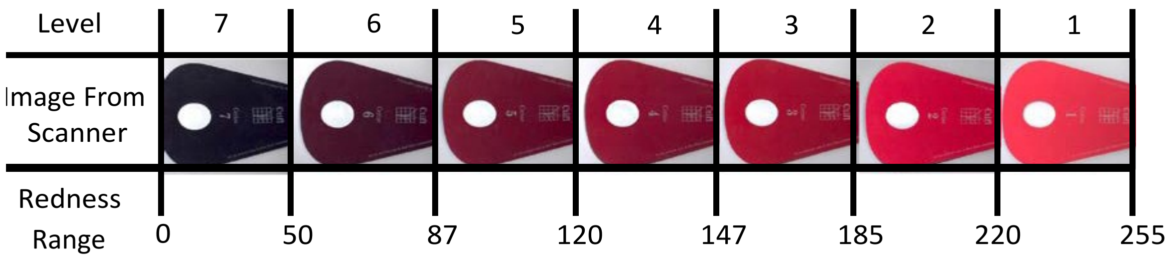

Figure 13. The defined quantitative redness range of seven standard cherry color levels, ranged from 0 to 255. The redness number between two adjacent levels is the boundary to distinguish them.

Fruit samples with different redness were scanned using the same device, and processed using the same color detection algorithm. The detected redness of a fruit sample was compared to the redness range of seven standard levels for determining its color rating. For example, a cherry sample with a redness value of 160 would be rated as a level 3 fruit based on this method (redness range: 147-185).

We have used the developed algorithm to rate redness levels of 175 cherry samples. At the same time, we had an experienced cherry researcher rate the same set of samples manually against the rating chart, and used his results as a benchmark to evaluate the automated rating algorithm. The comparison study showed that the accuracy of the developed automated rating algorithm was 75%. This accuracy was acceptable for the first trial of automated rating algorithm development.

We have found a couple of problems that might impede us achieving a higher level of color rating accuracy: (1) cherry skin glare disguised the original color of the fruit as shown in Figure 2; and (2) the skin color is often non-homogenous due to various reasons. For former, we plan to apply one or both of the following ways to reduce the glare effect: using software to detect glare automatically, then eliminating the glare area for color rating; and/or trying polarized filters to reduce the glare. The possible solutions to the second problem were: using only middle part of a fruit image for color rating; or taking pictures of a fruit from different angles, and then combine all images to have a final rating.

Figure 14. Glare effect showed on the skin of a fruit. The skin color was bright in middle, and darker on the circumference.

We are currently working on solving problems with scanner data, and expect to achieve a higher rating accuracy. Afterwards, we plan to process the data obtained from different light sources (color temperatures; 5400 K and 6500 K). We are expecting to achieve a satisfying accuracy by adding lighting change adaptability to the developed algorithms. The test results will reveal whether this technology would be promising for outdoor applications. If the results were positive, the developed algorithms would be tested in outdoor environments in the next stage of research.

Size Measurement

We have been working on the size measurement for a single cherry fruit. Three methods have been tested: rotation measurement, circle measurement, and ellipse measurement. The width (in mm) of 20 cherry samples was measured using both a caliper and three test methods. The caliper data were used as the true size data to evaluate the automatically measured data using three mentioned methods. Table 1 summarizes the measurement accuracies. All three methods had almost the same standard deviation of measurement error, but the ellipse measurement method had the smallest average error. Therefore, we plan to use the ellipse measurement method for further development.

Table 2. Measurement accuracies for single cherry size

Method	**Average Measurement Error (mm)**	**Standard Deviation of Measurement Error (mm)**
Rotation	-0.64	0.63
Circle	-0.71	0.69
Ellipse	**-0.01**	0.64

The preliminary tests showed relatively high accuracy for automated size measurement. However, we still need more tests to check the robustness of the algorithm. On the other hand, an accurate size measurement is subject to the accuracy of cherry segmentation from a background. We are now working on developing an automatic cherry segmentation algorithm. If the algorithm were proved fast and robust enough, it could help to realize a rapid size measurement for multiple cherries.

CONTINUING PROJECT REPORT **YEAR**: 2

Project Title: Economic analysis of technology adoption by Washington apple growers

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Cooperators: Tom Auvil – WTFRC
Karen Lewis - WSU Extension
Norman Suverly - WSU Extension

Total project funding request: **Year 1**: $23,368 **Year 2**: $17,036

Other funding sources: None

WTFRC Collaborative expenses: None

Budget 1

Organization Name: SES-TFREC-WSU **Contract Administrator:** **Ben Weller**
Mary Lou Bricker

Telephone: **(509) 335-5557** **Email address:** **wellerb@wsu.edu**
(509) 335-7667 **mdesros@wsu.edu**

Item	**2010**		
Salaries	0		
Benefits	0		
Wages	15,558		
Benefits	1,478		
Equipment	0		
Supplies	0		
Travel	0		
Miscellaneous	0		
Total	17,036		

Footnotes:

OBJECTIVES

1. *Evaluate the economic and managerial factors that contribute to a grower's decision to adopt automation and mechanization technologies.*
2. *Use the data collected during this project to support other educational programs, decisions aids focused on technology adoption*
3. *Establish a program for continuously collecting production and management data from tree fruit growers*
4. *Disseminate research results to tree fruit growers, packing houses representatives, researchers from other disciplines and interested parties*

SIGNIFICANT FINDINGS

Analysis of the survey results has begun. Below are tables showing summary statistics for several variables of interest.

Table 1. Orchard Structure

	Frequency
Planar, angled	53
Planar, vertical	80
Round	205
Other	42

Table 2. Platform Type

	Frequency
Self-propelled (gas)	3
Self-propelled (diesel)	11
Self-propelled (electric)	0
Pull-behind	16
Other	9

Table 3. Platform Use

	Average	Range
Years of use	7.4	0 - 50
Number of platforms in orchard	1.3	0 - 4
Number of people per platform	3.8	0 - 10
Planning to buy a platform in next 12 months	Yes: 9	No: 250

Table 4. Reasons for Using Platforms*

	Frequency
Increase in worker productivity	33
Improve worker safety	22
Easy for workers to operate	18
Purchase cost is recoverable	19
Improvement in quality of work	21
Other: Speed	1

*Reasons were rated as "Very Important"

Table 5. Reasons for Not Using Platforms*	
	Frequency
Orchard architecture is not suitable	152
Purchase cost is too high	110
Steep slopes in orchard	82
No improvement in worker productivity	62
Maintenance/repair costs are too high	44
Limited availability	28

*Reasons were rated as "Very Important"

Table 6. How are Workers Paid?			
	Hourly	Piece Rate	Other
Pruning	23	7	1
Training	19	4	--
Blossom thinning	3	2	--
Green fruit thinning	15	5	--
Scouting for pests and/or diseases	--	--	--
Pheromone placement	11	1	--
Trellis construction	13	--	--
Harvest	--	2	--

Table 7. Sources of Information for Machinery Purchases	
	Frequency
Other growers	188
Family members	87
WSU extension/research	88
Non-WSU extension/research	59
Tree fruit related conferences/workshops	106
Field days or farm tours	115
Internet based resources	57
Industry publications	99
Company selling machinery/equipment	79
Other: Fieldman	4

*Reasons were rated as "Very Important"

Table 8. Respondent Demographic Information	
Age	Mean: 58 Range: 25 – 88
Gender	Male: 282 Female: 21
Ethnicity	Caucasian: 270 Hispanic: 18 Asian: 2 Other: 25

Education	High school/GED: 51 Some college: 75 Bachelor degree: 110
Carry crop insurance?	Yes: 188 No: 112

METHODS

The first step in the analysis is the summarization of the survey responses to determine the general trends in the industry with regard to production practices. Then we will use probit model to determine the impact of grower and orchard characteristics on the likelihood of adopting platforms. This type of model uses the characteristics of the orchard (orchard structure, steepness of slopes, location within state) and the grower (age, education, sources of industry information) to estimate the probability that platforms are used on a given orchard. The survey responses comprise the data set and results from the model will indicate which factors are correlated with platform use and which are not. This type of model estimation can reveal more correlation than just looking at the raw data alone.

RESULTS AND DISCUSSION

Final estimates from the logit model are not ready for discussion at this time. However, we wanted to highlight some of the information gathered in the survey using cross-tabulation tables. One of the issues we were interested in understanding more completely was growers' reasons for not using platforms.

The survey asked growers to rate different reasons for non-use as very important, somewhat important, or not important in their overall decision to not use platforms on their orchard. Three of the most commonly cited reasons for not using platforms are non-suitable orchard structure, purchase cost is too high, and slopes of the orchard are too steep (see Table 5). While the high purchase cost reason given by growers for not using platforms is determined by grower-specific production costs, the two reasons given for structure and steepness of slopes are based on physical limitations of the orchard. Table 9 shows raw data counts for platform non-use by orchard structure across-tabulated by suitability of structure. Among growers not using platforms, but having strictly planar structures, 60% cited an important reason for not using platforms is the suitability of their orchard structure. The percent of growers citing this reason when their orchards are comprised of strictly round structures is higher 73.5%. The percent of growers citing non-suitable orchard structure and also having strictly planar orchards was surprising, given that platforms tend to be most efficient when used with planar structures.

This cross-tabulation of the data suggests grower perceptions of the suitability of their orchard for platform use may not be in line with those of platform designers. However, further investigation of this platform adoption issue, along with other information given in the survey results, is necessary to more accurately understand the survey results. Further results and discussion of this issue and others will be given in the final report.

Table 9. Type of Orchard Architecture by "System not Suitable" (for those not using platforms)

Architecture type	Count of orchards not using platforms	Orchard system not suitable*	% who indicated orchard system is not suitable
Strictly Planar	30	18	60.0%
Strictly Round	132	97	73.5%
Strictly Other	34	20	58.8%
Both Planar and Round	43	34	79.1%
Both Planar and Other	1	1	100.0%
Both Round and Other	2	1	50.0%
Planar, Round, and Other	2	2	100.0%
Total	244	173	70.9%

*Orchard system not suitable was determined by any response of either "Somewhat Important" or "Very Important" as a reason for not using a platform.

CONTINUING PROJECT REPORT **YEAR**: 1 of 3

Project Title: Technology Roadmap Support

PI: James Nicholas Ashmore
Organization: James Nicholas Ashmore & Associates
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Address: 400 North Capitol Street, Suite 363
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Cooperators: None

Total project funding request: **Year 1**: $33,000 **Year 2:$33,000** **Year 3**:$36,000

Other funding sources None

WTFRC Collaborative expenses: None

Budget 1
Organization Name: James Nicholas Ashmore & Associates
Contract Administrator: James Nicholas Ashmore
Telephone: **Email address:**

Item	2010	2011	2012
Salaries	$33,000	**$33,000**	$36,000
Benefits			
Wages			
Benefits			
Equipment			
Supplies			
Travel			
Miscellaneous			
Total	$33,000	**$33,000**	$36,000

Objectives:

1. To protect funding for ongoing research programs and to seek funding for new proposals identified as significant and beneficial to the Washington tree fruit industry;
2. To work with the Northwest Horticultural Council to insure that Commission research initiatives are integrated with and complement other tree fruit industry goals and objectives;
3. To continue cooperative efforts with the Northwest Horticultural Council, the U. S. Apple Association, and other specialty crop stakeholder groups in working with the Congress and the Administration in their efforts to reauthorize the General Farm Act; and to seek collaboration and assistance from other agricultural groups on shared concerns, and work to educate the Congress, the Administration, and the public about the significant benefits accruing from the Specialty Crops research programs as well as emphasizing the unique position of the Washington tree fruit industry and its economic importance to the Region and to the nation;
4. To insure that Federal research activities and requests for research proposals are strategically targeted and responsive to the needs of the Washington state industry and to insure that the Commission has the flexibility to choose to participate fully in the process;
5. To keep the Commission informed of developments in the Congress and the Administration that impact on ongoing and/or future research funding;
6. To pursue specific activities related to high priority research initiatives, including but not limited to the following:
   a. USDA-ARS apple rootstock breeding program, Geneva, New York;
   b. Expansion and enhancement of pear genomics, genetics, and breeding efforts and insure that those efforts address the needs of the Pacific West Region;
   c. Development and implementation of the newly-funded Roadmap project to identify and prioritize engineering technology research to develop new pesticide application technology and its implementation for orchard structures;
   d. Expansion of automation and precision agriculture research efforts that will benefit the Pacific Northwest; and,
   e. Expansion of research and extension efforts in sustainable tree fruit production and handling, including the implications for proposed regulations affecting such handling.

Significant Findings/Results (To Date):

- The Administration's budget request for the current fiscal year was sufficient to allow for continued funding for ongoing research programs;
- Both the House and Senate have completed committee action on the various appropriations bills; however, these bills have not come to the Floor and none has been enacted;
- As such, funding for the Federal government is continuing pursuant to a "Continuing Resolution that provides funding through December 3, 2010;
- These bills do in fact continue funding for important research programs; the Report to accompany the Senate bill contains language requested by Senator Murray and based on material worked on by the Commission Manager and Dr. Mike Willett of the Northwest Horticultural Council directing USDA to develop a roadmap or long range plan detailing steps to enhance pear genome, genetics, breeding research that will address the needs of the Pacific Northwest Region;
- It is not as yet clear how the Congress will handle these bills in the Lame Duck Session; however, action of some type will be necessary to allow the government to continue operations past the expiration of the Continuing Resolution; it is likely that the outcome of the November Elections will define how the Congress moves on these bills;

- Both the House Agriculture Committee and the Senate Committee on Agriculture, Nutrition, and Forestry began preliminary hearings leading to reauthorization of the General Farm Act, which expires in 2012;
- The Specialty Crops industry has been responsive to the leadership of Chris Schlect of the Northwest Horticultural Council to reestablish and strengthen its cooperative efforts to address specialty crops issues in the various farm act titles; I have worked closely with senior staff in this effort to insure that specialty crop interests are heard and that the specialty crops industry has a strong seat at the table;
- Much has occurred over the past several months in the environmental area and I have worked with Dr. Willett and the Commission Manager and with senior congressional staff to insure that EPA and USDA are responsive to specialty crop interests and that those interests are treated equally to that expressed by the traditional program crops;
- I have emphasized to related agricultural groups like CropLife America our support for the roadmap process that was funded to define an approach to research needs in technology to address modernizing and enhancing pesticide spray application technology;
- Based on the work that I have done to date and working with the Manager and with other related groups like the Northwest Horticultural Council, it is clear that the Washington State Delegation and senior staff in the House and Senate clearly recognize the importance of specialty crops research and that they stand ready to work together to help us and to the extent possible protect our interests;
- We have, I believe, significantly enhanced our relationship with the Northwest Horticultural Council and with other related groups; we have continued to strengthen our cooperation with them on a number of issues that are related to our interests;
- As a result of the continued efforts of the Commission Manager and others in the tree fruit industry, we have worked to reinvigorate that U. S. Apple Association's Research Subcommittee and its commitment to these important research efforts; this will be helpful over time in working with Congress and emphasizing how the Roadmap process fits into and complements the Specialty Crops research programs, especially the emphasis on genome, genetics, breeding research and engineering research in the areas of automation and sensor technology;
- I am continuing to work with the Commission Manager and Dr. Willett on the issues that have surfaced with respect to the validity of the science used by EPA in proposing a number of environmental initiatives dealing with pesticides that could, if implemented, significantly impact on agricultural operations in the State of Washington; these initiatives include but are not limited to proposals affecting spray drift or proposals to respond to Biological Opinions issued pursuant to the Endangered Species Act(ESA);
- I worked with Dr. Willett and with CropLife America to arrange for Dr. Willett to attend the annual meeting of CropLife America and participate in a discussion of the issues that have surfaced with respect to the implementation of ESA; those discussions focused on a number of efforts to address different aspects of these issues and how to insure that agencies have access to and use science in an objective and transparent manner;
- Our involvement in leading the successful efforts to develop the National Technology Roadmap for the Tree Fruit Industry continues to have great dividends and we have (largely as a result of the efforts made by the Commission Manager), established strong personal relationships with a number of senior officials within the current Department of Agriculture; we are beginning to see evidence that the progress that we are making in research is being included in the President's budget requests;
- Given the strong emphasis on controlling Federal spending and the widespread media coverage focusing on the Federal deficit and its impacts on the economy, we may face problems in the future in determining the tradeoffs that might become necessary;

- The President's Deficit Reduction Commission is expected to complete its work and submit its recommendations in December of this year; at this point, it is unclear as to how the Congress will deal with those recommendations;
- It does seem clear that there will be limits placed on discretionary spending, although it also appears likely that defense spending and homeland security spending could be exempt from those limits;
- I fully expect that there will be at a minimum a continuation of efforts to restrict "earmarks" and their use in appropriations bills; in response to this particular aspect of the issue, we have worked carefully to encourage processes that lead to the inclusion of our priorities in the Administration's budget requests; we have also continued to emphasize our commitment to competitive awards for research and that such research be designed to address the common needs of a wide range of agricultural groups;
- Our approach and the benefits that we have achieved is best illustrated by the actions of the Senate Appropriations Committee taken at the request of Senator Murray to include "Report" language asking USDA to provide information as to the planning and costs associated with enhancing pear genome, genetics, breeding research;
- There are significant other benefits that result from our approach to the process and we have enhanced our relationships and opened and\or expanded channels of communication between the Commission Manager and the Northwest Horticultural Council with senior congressional staff and senior aides at USDA. We continue to be respected for our openness and transparency and our commitment to competitive funding for research; and,
- Working with the Commission Manager, U.S. Apple Association, and Phil Baugher of Pennsylvania and working through the office of Representative Doc Hastings and others sought to emphasize the importance of the USDA-ARS apple rootstock breeding program in Geneva, New York.

Methodology:

I have sought to insure that the methodology and strategy that we use should reflect who we are and by extension show by example what we are seeking to achieve. From the beginning of this process some years ago, we have been consistent in dealing with the Administration, Congress, and associated agricultural interest groups. We have earned a reputation as a group committed to sound science, as a group committed to competitive research funding, and a group committed to transparency and common sense.

That methodology/strategy has served us well. We are making steady progress and we have helped insure that our industry understands and communicates well together and with the Administration and the Congress.

Because of this basic approach and our commitment to working on the basis of science and fact and because of our efforts to work on a bipartisan, nonpolitical basis, we are well-suited to go forward regardless of the outcome of the November Elections.

I will continue to employ the same methodology and strategy that has been successful in getting us to this point with respect to implementation of the National Technology Roadmap for the Tree Fruit Industry.

Simply put, this strategy has emphasized the Commission's continued commitment to openness and transparency as well as the Commission's strong commitment to competitive research funding that will insure that we have the best available scientists working together to accomplish our common goals.

I have and will continue to reach out to and work with the Northwest Horticultural Council, the U. S. Apple Association, and other specialty crop groups so that we can speak with a common voice and move to address shared, common problems in a manner that satisfies current law and insures that there is research collaboration and partnering that will provide a multidisciplinary approach that can produce results that provide benefits to a wide range of commodity groups in a number of different regions of the country. In taking this approach, it is my hope that we will strengthen the relationships and expand our base so that we will be better prepared for future debate on these issues when the Congress continues its discussions of the issues associated with reauthorization of the General Farm statute.

I expect to continue to work to inform and educate, to seek help where necessary and appropriate, and work carefully to help insure that we are providing full and detailed information to those people that we are asking to help us.

I have sought to demonstrate the patience necessary to move the ball forward and to prepare the ground for future success, and I believe that as a result of this methodology and the full cooperation and leadership from the Commission and the Commission Manager that we are making real and defined progress and also setting ourselves properly for significant successes in the future.

I believe that this methodology and strategy are the primary reasons for building our reputation as a responsible partner, committed to fact-based, results oriented decision making in funding research programs to address our carefully defined needs.

Discussion/Going Forward

When the Congress returns for its Lame Duck Session after the November elections, it will face a number of issues, all of which are likely to be colored by the outcome of the elections. The two most significant questions that will come up are how to dispose of the pending appropriations bills funding the Federal government for the current fiscal year and also how to handle the question of possible extensions (all or part) of the tax cuts enacted in the previous Administration.

How the Congress ultimately decides these issues will have little if any direct impact on research funding priorities. Generally speaking, we are in a good position in the short term. The significance of the decisions on these issues lies in how they impact on or set the stage for policy positions that can be expected in the next Congress.

What I expect that we will face in the next Congress is concentrated emphasis on the economy, the budget deficit and its accompanying issues, and a general thrust moving toward tighter controls on Federal spending.

The next Congress will have to decide whether to act on the recommendations of the President's Commission on the Budget or move to the Budget Reconciliation process. In any event, there will be significant attention on the so-called "entitlement" programs and there is the strong possibility that traditional agricultural programs could be included.

In addition, the next Congress will grapple with efforts to reauthorize the General Farm Statute and is likely going to have significant budget limitations placed on that effort...

I expect that there will be continued interest in efforts to reduce and move toward elimination of "earmarks" in the appropriations process as well as continued interest in basically freezing nondefense and non-security discretionary spending.

Fortunately, we have been able to build a strong network that we can build on to help us defend the progress that we have made to date and, in carefully targeted instances, expand and take the next steps forward. The coordination among the specialty crops interests has to be a significant and important part of our efforts.

We also need to continue to build on our relationships with this Administration and continue to work with the Administration to insure that budget requests made to Congress continue the important work that has been done.

We do, however, have certain responsibilities in working with the Administration and the Congress in determining funding priorities. I believe that we need to work toward getting better data to show the economic and scientific benefits that have been achieved through the research efforts to date.

We also, I believe, need to “stay ahead of the curve” in determining how current research fits together and what additional research is needed based on the knowledge gained to date. In effect, we need to help make our “roadmap” into a reality that does in fact produce deliverables in the market place.

We also I believe should be aware of need-based research and the potential benefits that could be gained for the growers from working in this area. I believe, for instance, that there may be potential for research efforts to address new pest threats (APHIS/Homeland Security) and also for growth in engineering technology research to address environmental issues or food safety issues.

One of our more important efforts will be to help Congress and the Administration to work together to insure that USDA understands and implements the language (relative to pear genome, genetics, breeding research) included in Report to accompany the Senate agriculture appropriations bill. I believe that this approach addresses the concerns over “earmarks” and demonstrates the good faith effort of our industry in working with the Administration in going forward.

While there is no absolute certainty, it does appear that the next Congress will be focused in large part on the economy and the Federal budget and how it impacts on the economy. I strongly recommend that we begin preparing carefully for what I believe to be the coming debate.

We are, I think, uniquely well positioned to defend the progress that we have made. As I pointed out in my Continuing Report earlier this year, I would hope that we can come together to determine how we can best quantify the benefits that have accrued to us and others in the specialty crops research group. I think that our efforts in engineering and technology research are great examples of how we can show tangible benefits from moving to achieve meaningful research results and show how they can be brought into commercial use

We have friends, and we have an outstanding reputation. We have open channels of communication to the Congress on a bipartisan basis as well as to senior Administration staff. The next two years (the next Congress), will deal with very real, complex, and complicated issues that affect industry operations. It is important that we continue to stress our commitment to sound science, to competitive research funding, and the design and implementation of agricultural research that helps a wide range of crops in a cross-disciplinary approach. I appreciate the faith and support that the Commission has given to me, and I look forward to continuing to work closely with the Commission and the Commission Manager in these efforts.