Comprehensive Automation for Specialty Crops

Portfolio
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Comprehensive Automation for Specialty Crops (CASC) is funded by the USDA Specialty Crop Research Initiative—established by the 2008 Farm Bill—with 100% matching funds from industry and university partners.

CASC is a flagship project, with $12 million in total funding, dedicated to developing comprehensive automation strategies and technologies for the $18 billion U.S. deciduous tree fruit industry and the $17 billion U.S. nursery and landscape industry.

We are
• Multi-disciplinary—engineers, scientists, extension educators, growers, manufacturers
• Multi-institutional*—universities, government labs, companies
• Collaborating with nurseries and orchards—in California, Maryland, Oregon, Pennsylvania, and Washington—representing 74% of U.S. tree fruit production

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DEVELOPING A MORE SUSTAINABLE AND PROFITABLE U.S. SPECIALTY CROP INDUSTRY

CROP INTELLIGENCE
Plant stress & disease detection
Insect monitoring
Crop load scouting
Caliper measurement

AUTOMATION
Reconfigurable mobility
Accurate positioning
Augmented harvesting

TECHNOLOGY ADOPTION
Sociological implications
Value proposition
Outreach and extension

*PARTNERING INSTITUTIONS—Universities: Carnegie Mellon University (lead), Oregon State University, The Pennsylvania State University, Purdue University, Washington State University; Government Lab: USDA Agricultural Research Service Appalachian Fruit Research Station; Companies: Vision Robotics, Toro, DBR Conveyor Concepts, Trimble, Spensa Technologies
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Press reports on CASC
obotics experts at Carnegie Mellon University in Pennsylvania are confident they can develop a machine able to count apples in orchards in order to provide growers with accurate crop estimates and yield maps. And it may be feasible for the machine to estimate the size of the apples.

Dr. Stephen Nuske, project scientist at Carnegie Mel- lon’s Field Robotics Center, said a precise estimate of the crop could help growers and packers better plan for harvest and know exactly how many bins they will need in the various parts of the orchard and how much transport and storage will be required.

“Knowing those yields can really optimize the efficiency of their operations,” he said. “The other big thing we think it can be useful for is reducing the variability of crop efficiency of their operations,” he said. “The other big thing we think it can be useful for is reducing the variability of

An accurate count of the apples across the whole orchard would help growers and packers be well prepared for harvest.

by Geraldine Warner

The California company Vision Robotics began developing an automated apple crop estimation system six years ago with funding from the Washington Tree Fruit Research Commission. It was conceived as the first step in developing a robotic apple harvesting system. The company later was a cooperator in the national Comprehensive Automation for Specialty Crops project that was supported with federal funding. Now, Nuske and his colleagues, Dr. Sanjiv Singh and Dr. Marcel Bergerman, who are involved in the CASC project, have proposed an alternative crop estimation system. They have already worked on robotic crop estimation in strawberries, grapes, and other crops, and are confident that a commercial system can be developed.

Cultivars multiple images of each fruit as it goes by. A high-resolution camera is used to take images of the trees and vines and detecting the fruit and counting it,” Nuske said. CMU’s crop estimation system’s hardware consists of two high-resolution cameras with wide-angle lenses and two ring flashes on an aluminum mount. Nuske and Singh mounted the system on an autonomous orchard platform that they developed, which can travel down the rows at a consistently slow speed (about half a mile per hour). However, the system could be mounted on a manually-driven vehicle.

As the system goes down the row, it photographs the trees, taking one image per second, which means it captures images of each fruit as it goes by. A high-precision GPS device is used to determine the exact location of each apple and ensure an apple seen from both sides of the tree is not counted twice.

Nuske said it would be easy to calculate the size of the fruit. “All you need to know is the distance of the apple from the vehicle and the size of the apple in the image.” The speed it travels down the row could be increased if it proves possible to have an accurate count with fewer images or if the cameras could capture images faster.

There’s no reason, Nuske said, why it couldn’t ultimately it could do the job ten times as fast.

Night

When the scientists began their crop estimation work on strawberries, they operated the system during the day, but found that it performed more consistently with controlled lighting at night. The images are in color. The software uses hue, saturation, and value to distinguish red apples from other objects in the orchard, such as wires, trunks, branches, and foliage. A different method, which uses color intensity, is used to detect green apples. Apples have a stronger green color than foliage. Light reflected from the objects in the image is used to distinguish the shape and location of the apples.
Results from orchard trials show that the robotic yield estimator is most accurate in high-density, trellised plantings with two-dimensional trees, where most of the fruit are visible. It is far less accurate in traditional plantings with widely spaced large trees where much of the fruit is hidden from view, or “occluded,” to use the scientific term.

“We can count all the visible apples,” Nuske said. “But there’s no method where you can count an apple that’s not visible.”

However, if the number of hidden apples is consistent, which was the case in the trials, the estimation system could be calibrated by having humans count all the apples on sample trees then calculating the percentage of apples the machine is missing.

This would not necessarily have to be done each year or for each orchard, Nuske said. Similar orchards might be able to use the same calibration factor. In their grape studies, they worked in two similar-styled vineyards—one in New York, and the other in California—and were able to use the same calibration in California as in New York without needing to take manual samples again.

The scientists tested the apple yield estimation system in 2011 with Red Delicious and Granny Smith apples at a Washington State University research orchard near Wenatchee. The estimate for red apples on a high-density system was quite accurate at 3.2 percent lower than an estimate made by humans counting each apple. They also tested it in a block of green apples, which had not been fruit thinned, had large clusters of apples and more foliage. As a result, many apples could not be detected because they were hidden by other apples or leaves. In that block, the machine estimate was 30 percent lower than the human count, but, after calibration, it was within 1.2 percent of the human count.

Further tests were conducted with Honeycrisp this September at Pennsylvania State University’s Fruit Research and Extension Center in Biglerville. Data are still being analyzed.

The four-year CASC project will end this year, but Nuske will continue to work on generic crop estimation systems for another three years with USDA funding. The National Wine and Grape Initiative is supporting the grape research and is interested in seeing a crop estimator commercialized.

Nuske suggests that not every grower would purchase a yield estimation system. Rather, a service company might buy one and do yield estimation for growers on a contract or service basis.

“The yellow circles represent the locations of apples, as calculated by the software. Images are taken at night, under controlled lighting.

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Robots replacing fruit pickers? Not quite, but a new machine is changing the industry

By Melanie Tubbs
Story Updated: Sep 23, 2012

PASCO, Wash. -- Apple harvest should begin next week and KEPR has continued to cover major concerns about a shortage of pickers for our crops here in Eastern Washington. Now, there might be a solution. A new fruit-picking machine is being tested in our area.

It's sunrise at Hayden Farms in Pasco. Chatter of birds nearby. But on Wednesday morning, wheels, tubes and exhaust cram the orchard.

It's called the DBR. It stands for Dietrich, Brown and Rasch, the last names of the engineers of the machine. It's robo-farmer of sorts. A newly-engineered machine to assist fruit pickers. Grower Denny Hayden is testing the DBR out.

Grower Denny Hayden tells KEPR, "We're not picking every fruit. The fruit with the proper maturity, proper background, and fruit color." Denny has struggled to keep enough workers through the harvest season. "We've been right on the edge all year long and it's been like that for a couple years, and we don't anticipate it going better." Recent reports found there could be 40% fewer Ag workers this year over last. A machine like this could make all the difference. The DBR could cut labor costs in half for farmers. Saving thousands of dollars.

Denny explains, "With apples, 30-50% of our costs are labor costs in cherries, it's even higher." Labor costs can get passed on to the consumer. Instead of a human, the machine takes the apples, sucks them back through a tube and carefully places each one in a bucket. The platforms move up and down, forward and back to reach for fruit. The DBR carries five pickers as it moves down the row. It doesn't even need a driver.

"We're not out there climbing ladders, carrying ladders, not carrying around a big bucket of fruit," Denny says. But this machine wouldn't replace workers all together. He continues, "We're just making the human more efficient." That efficiency could open the door for more people who could never do this kind of work before. "Because it's a less physical action." That could put more Americans to work. Denny nods, "Maybe we're going to be able to use more of a domestic force." Denny hopes in a few years, a machine line the D-B-R could help cut a third of his payroll. "We're trying to figure it all out still. This is the beginning stages," He says.

Changing the face of one of the oldest industries we know. There are only two DBR's in the nation right now. One is being tried out throughout Washington orchards and the other in Michigan.
Robotic harvester would be costly

Robotics expert Dr. Sanjiv Singh says fully automated robotic harvesting systems are looking more feasible technologically than a few years ago, but whether they would be robust enough for orchard work and affordable to the growers is still in doubt for the time being.

Singh, a researcher at Carnegie Mellon University’s Robotics Institute, is leading a multistate project on Comprehensive Automation for Specialty Crops, which aims to develop methods to improve production efficiency, identify threats from pests and diseases, and respond to food safety hazards.

What it doesn’t aim to do—at least, not yet—is develop a robotic apple harvester. Singh said when the CASC project began in 2008, the scientists involved decided not to work on automatic harvesting. It would be such a huge endeavor, they agreed, that it would overwhelm the rest of the project. Not only that, but what would be the use of developing a machine that cost $2 million dollars? Or could only pick one apple every ten seconds (10 times slower than a human)?

“The gee-whiz factor runs cold pretty quickly,” he said. “We could have done it, but we needed it to be all three of these things for it to be a success: affordable, robust, and technically feasible. Those are the reasons I personally think it’s not a short-term or even medium-term solution. It would require some significant funding, and I don’t know if there are deep enough pockets to go after that.”

CASC faculty decided instead to work with DBR Conveyor Concepts in Michigan who are developing a harvest-assist machine that improves harvest efficiency by eliminating the need for workers to climb ladders. That’s the type of technology that will reach growers quicker, Singh points out. Tests with the DBR last season in Washington State showed that workers were 20 percent more efficient working with the machine than when picking fruit conventionally. Singh said the developers and scientists think it reasonable to expect that the machine could increase worker efficiency by 100 percent within three years, which would mean the grower could get by with half the number of workers.

“That’s something that people can go to the bank with,” he said. “There’s a lot more that can happen to the machine.”

Automated harvesting

Meanwhile, scientists at Carnegie Mellon are wondering, four years after the CASC project began, whether the time is ripe to begin looking at fully automated harvesting. Tree architecture is changing, with more growers adopting formal training systems where there is less obstruction of fruit by the foliage, and the cost of technology continues to decrease.

“We may start to consider this,” Singh said. “We’ve been doing some experiments in our lab, trying to see how hard it is.”

For example, they’ve done trials with industrial robotic arms—the kind that would survive repeated motions—to find out how precisely they can locate something and reach out and grab it.

“When you watch them, they’re cartoonish,” Singh said. “Right now, they have slow, deliberate motions, and the kinds of grabbers we have are pneumatic and don’t look quite right.”

Whereas a person who’s good at picking might pick an apple per second, these robotic arms might take ten seconds per apple.

But the good news is that the robotics are far cheaper than they used to be. Five years ago, one robotic arm might cost $150,000, which didn’t make economic sense. Now, they are ten times cheaper.

(Continued on page 8)
Singh said these are informal experiments to gather preliminary data that could be used in writing a proposal. "We want to make sure we don't oversell the technology," he said. "We want to make sure when we come out there that people think it's credible. We've taken a pretty conservative approach to this."

Once a project is launched, he thinks it could take three to five years to develop a system with the right accuracy, speed, and price.

**Vision Robotics**

One of the important aspects of a harvesting system is the ability to locate the apples on the trees. Six years ago, Vision Robotics of San Diego, California, began a project to develop a robotic harvester. Other manufacturers who had attempted robotic harvesting had run into problems with end effectors that tried to locate fruit as they picked it. Vision Robotics took a two-step approach. One robot would act as a scout, develop a three-dimensional map of the fruit and interfering branches, and work out a picking strategy for a separate machine that would come along later and pick the fruit.

The Washington Tree Fruit Research Commission provided $283,000 initially to Vision Robotics to develop the orchard scout, while the California Citrus Research Board paid a similar amount to the company to develop a citrus scout. Vision Robotics was never able to secure funding to develop the harvesting part of the system, but saw potential for the scout as a crop estimating and yield mapping tool.

When the CASC program began, Vision Robotics became a collaborator. Carnegie Mellon's Robotics Institute has since taken over the scout project. Singh said they are working on making it more compact and lighter so it would be cheaper and easier to pull with a tractor. They have also integrated the scout with an autonomous orchard vehicle that they've developed. The university is looking for a partner to commercialize it.

Tony Koselka, founder and chief operating officer of Vision Robotics, said his company is still interested in developing a robotic harvester, but it would be an expensive project that would be best tackled by a consortium because various scientists around the country are making progress on different aspects of it. It would be a multi-million-dollar project.

He believes it is technologically feasible, and perhaps even cost effective, but he thinks it would be difficult. Manipulating the apples without damaging them is the hardest part. Apples can't just be plucked from the tree. It's challenging to have a machine grab apples from a variety of different angles and replicate the way a human lifts and turns them to detach them from the tree. The project would be easier if all the orchards had formal training systems where all the fruit was visible and hanging vertically, he said. The scout would be 100 percent accurate, and the harvester could have shorter arms and could pick all the fruit from the same orientation.

Having a scout to map the fruit before harvesting might not be necessary in orchards where all the fruit is immediately visible, but a scout would make it more efficient, Koselka said. "The biggest factor is how fast you can get the fruit off the tree. If the scout gets you 25 percent more efficiency, that's enough to pay for the cost of it."

Initially, a robotic harvesting system might not save growers money, but it would reduce their labor needs. Koselka said the economics are less favorable in apples than in citrus, however, because citrus is harvested for ten months of the year versus a few weeks for apples. Machines for apple harvesting might need to be multipurpose so they can be used for other jobs such as pruning, he said. Vision Robotics has developed a robotic pruner for grapevines, which should be commercialized within the next two years.

**CROP estimating project**

Dr. Manoj Karkee, engineer at Washington State University's Center for Precision and Automated Agricultural Systems, is working on a machine-vision system to improve apple crop estimating. He has designed an over-the-row platform to carry a color camera, a three-dimensional camera, and an orientation sensor along apple rows.

When he tested the system in an orchard of Allan Brothers, Inc., in Prosser, Washington, he was able to capture images of both sides of the trees, which allows better identification of apples than when images are taken from only one side. The sensor records where the camera is oriented so that a 3D map of the fruit can be created. Mapping fruit in 3D should help eliminate duplicate fruit counts and improve the accuracy of the crop estimate, which can be made on a block-by-block basis, Karkee reports. The system should be able to identify an apple that is 10 millimeter (3/8 inch) or larger.

Karkee, who will receive $34,402 in funding from the Washington Tree Fruit Research Commission for the project this year, plans to redesign the platform to make it lighter and easier to operate and to include lighting so it can operate at night. He will also investigate blowing air onto the trees to move the leaves and improve the ability to detect fruit.

Karkee is also exploring the use of 3D cameras in an automatic pruning system for apples with the aim of reducing the manual labor needed for pruning. The system would employ machine vision to identify where on the trees cuts should be made. In tests, the system was able to do that with 90 percent accuracy.

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"The gee-whiz factor runs cold pretty quickly." —Sanjiv Singh

WSU engineer Manoj Karkee is designing an over-the-row crop estimating system.
Focus Shifts to Full Automation

WSU is developing a roadmap for research on mechanical harvesting of apples.

by Geraldine Warner

Faculty at Washington State University’s Center for Precision and Automated Agricultural Systems plan to focus the bulk of their efforts in the future on the pursuit of a fully automated apple harvesting system. And they’re compiling a roadmap to guide their efforts and to help secure funding for the research.

Forecasts of large tree fruit crops in the Pacific Northwest this year have got growers wondering how they’ll harvest them. This season could see record cherry, apple, and pear crops. Increased production coincides with a smaller number of migrant workers entering the country from Mexico, and there is no immediate prospect of federal legislation that would help increase the labor supply.

At least two machines are under development in the United States that would relieve pickers from the task of climbing up and down ladders to pick fruit and then empty the contents of their picking bags into bins. This could increase worker productivity as well as expand the potential labor pool to the less physically able.

“Most new acreage being planted in the Columbia Basin is a formal system.”

—Karen Lewis

But scientists say the increase in productivity from such labor-assist technologies is modest in relation to the potentially huge shortage of workers and that such machines are just a stepping stone to the fully automated systems that the industry needs.

Karen Lewis, WSU extension tree fruit specialist and an associate director at CPAAS, said that it was during a trip to the World Ag Expo in California earlier this year that a group of industry representatives and scientists realized that research efforts in automation could be more effective if the center devoted 60 to 70 percent of its efforts on solving the one problem—moving from human-assisted technology towards fully mechanized harvest. CPAAS has an interdisciplinary team with horticulturists, engineers, computer scientists, and extension specialists who are working to develop technical solutions for tree fruit production.

Lewis said this shift in focus will require a major shift in the industry towards simple orchard systems that will be compatible with automated harvest. The formal system used at Auvil Fruit Company’s ranch at Vantage, where each limb of the tree is trained along a trellis wire, is the one where successful automation is likely to come the quickest. Success there should help get the industry excited to see the possibility, she said.

 Similar systems are now being adopted by other major grower-packers in Washington, she noted. “Most new acreage being planted in the Columbia Basin is a formal system. It’s not so random any more, and formal is what you need for automation.”

However, the other 90 percent of the acreage in the state would still need to be converted. Even at 5 percent per year, that would take 20 years.

Roadmap

Dr. Qin Zhang, director of CPAAS, said the university’s role will be to create knowledge and core technologies, and deliver that knowledge to manufacturers who can deliver the product for solutions that offer near-term impact and those we need to invest in now or we won’t see the progress that’s necessary in the next five or ten years.

The Research Commission is providing almost $54,000 in funding for the first year. Graduate student Mark DeKleine, who is working with professor Dr. Manoj Karkee on the project, told the commission that the aim is to develop a system to harvest undamaged fruit for the fresh market using as many off-the-shelf components as possible.

The Research Commission is providing almost $54,000 in funding for the first year. Several years ago, the commission gave funding to the California company Vision Robotics to work towards robotic harvesting. Initial efforts focused on developing a machine vision system to locate the fruit, which was seen as a necessary precursor to a harvesting system.

Dr. Jim McFerson, manager of the Washington Tree Fruit Research Commission, said the commission is willing to consider investing in any kind of technology that offers potential impact, whether long- or short-term.

“I think it’s a mistake to identify or to qualify engineering solutions as more expensive. If you look at what we spent on codling moth over the past ten years, you would have to say that’s an incredibly expensive project.”

“Fore that the commission and its committees are taking a balanced approach and looking for solutions that offer near-term impact and those we need to invest in now or we won’t see the progress that’s necessary in the next five or ten years.”

Dr. Qin Zhang, director of CPAAS, said the university’s role will be to create knowledge and core technologies, and deliver that knowledge to manufacturers who can deliver the product for solutions that offer near-term impact and those we need to invest in now or we won’t see the progress that’s necessary in the next five or ten years.
Bin dog under development

An intelligent bin-moving system could reduce harvest labor needs.

by Geraldine Warner

An intelligent bin dog system—a self-propelled bin carrying system that could follow fruit pickers through the orchard—is one of several labor-saving devices that scientists at Washington State University's Center for Precision and Automated Agricultural Systems hope to develop.

Dr. Qin Zhang, director of the center, which is based in Prosser, envisions that the electric bin management system would carry an empty bin into the orchard and follow the pickers until the bin was full. It would then transport the full bin to a central collection station. It would be operated remotely by a picker who would signal when the full bin needed to be removed and a new empty bin was needed.

The goal is to improve the efficiency of picking in both cherry and apple orchards by eliminating the need for pickers to walk to the bin and back to empty their picking bags.

Karen Lewis, WSU extension tree fruit specialist, who is also working on the project, said walking from the ladder to the nearest bin and back could account for as much as 20 percent of the total time a worker spends picking, depending on the variety, crop load, and density of bins. The bin dog would likely be most useful in an orchard being color picked where the bins are relatively far apart. The picker would be the master and the bin mover would be the slave, and they would be connected electronically.

The system would also eliminate the need for bins to be moved around by workers driving tractors and trailers, which would be another savings. However, one carrying system would be needed for each bin. The project, which will receive almost $70,000 in funding from the Washington Tree Fruit Research Commission in the coming year, is in the design phase. The next step is to develop a prototype to test in Washington orchards and figure out how it can work on sloped ground.
After five weeks of testing in Washington State apple orchards last fall, the DBR harvest-assist system has been extensively modified for further tests this season in preparation for commercialization in 2013.

The system, developed by DBR Conveyor Concepts in Michigan, is on a platform and has four flexible tubes into which workers place apples as they pick them. The apples are transported through the tubes by vacuum into a bin on the platform. A straddle trailer at the back carries empty bins that are loaded onto the system as full bins are discharged in the row.

Mike Rasch, a partner in DBR, believes that a 50 percent increase in efficiency is possible, compared with traditional apple picking from ladders. In a fruiting wall system, the gain in efficiency could be 80 percent or more.

Karen Lewis, Washington State University extension tree fruit specialist, who has been testing a prototype built for Washington conditions, said last year’s trials focused primarily on how to reduce bruising to the 5 percent tolerance level. The harvesting system was tested with many different apple varieties, and an Impact Recording Device was used to measure impacts as it traveled through the system. The IRD showed that impacts were highest in the machine’s tubes that carry apples up to the platform, though not all the impacts caused damage.

A comparison of Fuji apples picked with workers using the harvesting system versus workers using ladders showed that there was bruising of fruit even when it was harvested in the traditional manner, Lewis reported to the Washington Tree Fruit Research Commission.

DBR field validation work is supported by the Comprehensive Automation for Specialty Crops project, in which she is a collaborator. Equipment costs for the DBR 2011 prototype that was built to Washington specifications were shared by CASC and the Washington Tree Fruit Research Commission.

**Modifications**

Rasch told the Good Fruit Grower that he and his colleagues have made a number of modifications to the system since last season. These include:

- A self-leveling trailer to ensure that the bins are evenly filled with fruit, even when the system operates on slopes. The platforms will stay perpendicular to the trees, rather than the ground, helping with the positioning and access to the tree and fruit.
- A shelf above the elephant ears in the bin filler to ensure even filling of the bins even when the volume of fruit being picked varies from one side of the row to the other, or when picking outside rows.
- LED lighting, so that the system can be used for two shifts per day. Rasch said LED lighting is close to natural light and doesn’t cast shadows, and also has a low amp draw.
- A telescoping tongue between the tractor and the platform that can be retracted when turning rows.
- A remote steer/shuttle shift system on the tractor that can be operated from the platform to eliminate the need for a driver in the row, and a creep gear so that the tractor can move at about 0.2 miles per hour.
- Replacement of the safety rail with harnesses, which workers in Washington are more accustomed to.

Rasch said the system compared favorably with hand picking in terms of the quality of the fruit last season, but modifications have also been made to the fruit handling aspect. Each of the system’s four tubes can handle apples at a rate of up to two per second.

**More tests**

In August, the system will be tested in processing peach orchards in California. In late August and early September, it will be tested in California pear orchards. From the second week of September until the end of the season, it will be tested with apples and pears in Washington on more sloped terrain than last year.

Rasch said the system was designed to handle any round fruit or vegetable that’s not larger than the 4.5-inch diameter of the tube holes. However, it probably won’t be suitable for picking fresh peaches because friction between the fruit and the tubes removes the fuzz.

It has already been tested on Asian and European pears. If the European pears are oriented correctly, there seems to be no problem, but he’s not sure how well it would work if pears were put into the tube stem first.

“I think it’s all doable,” he said. “But it’s going to be a learning curve. I think it will be a landmark year to get it out and get some time on it.”

Another model of the system will be tested in Michigan this season. Though the state only has between 10 and 15 percent of a full apple crop, this will be a good season to test it, Rasch said, because all the crop is in the tops of the trees.

“It think it will really shine this year for that reason, but we won’t get the efficiency on it because of the limited crop.”

**Return on investment**

Rasch said more refinements might be made before the system goes on sale in 2013 at an estimated cost of between $85,000 and $95,000. The cost does not include a tractor to pull it. Phil Brown Welding in Michigan will manufacture many of the trailer and platform components, and DBR Conveyor Concepts will manufacture the vacuum and other components of the system.

Rasch expects the grower’s return on investment to be good. The system is designed so that the harvesting part can be separated and the platform used year round for such jobs as pruning, thinning, trellis tying, and hanging of pheromone dispensers. “It’s the whole gamut of things a grower has to do in the tops of the trees,” Rasch said.

The partnership has already been contacted by interested potential buyers both in the United States and abroad, he said. “The interest is there. We’re excited about where it’s going, and we feel good about what we’ve achieved so far.”

Collaboration with the Washington tree fruit industry, the Michigan Apple Committee, Pennsylvania State University, and the CASC project has helped move the project along more quickly, he said.

With labor availability becoming an increasing concern, Rasch senses a greater willingness among growers to consider mechanization. “Labor is an issue, and the industry seems to have turned the corner towards looking at mechanization. Labor is really going to dictate the need for it.”

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**Harvest/Postharvest**

The DBR harvest-assist system continues to be refined with commercialization in mind.

*by Geraldine Warner*

“*It will be a landmark year to get it out and get some time on it.*”
—Mike Rasch
Dr. Daniel Schmoldt, National Institute of Food and Agriculture staff director at the U.S. Department of Agriculture, has helped get the agency involved in President Obama’s National Robotics Initiative. The USDA has teamed up with three other agencies — the National Science Foundation, NASA and the National Institutes of Health — to collect proposals, small and large, for new uses of robotics in the civil sector. While the farming industry has been slow to pick up robotics in the past, Schmoldt says there are now ample opportunities for unmanned systems to plow — or till, or harvest — their way into the industry.

Q: How has the market for unmanned systems and robotics in agriculture evolved?

Because of the farm workers unions and things like that back in the ‘70s, there was a strong backlash against mechanization, because it was eliminating jobs for farm workers. A lot of the robotics that would have ensued and developed from that really didn’t have a chance, because the people that were doing the engineering and technology development were turned away from that. The funding wasn’t there; the incentives weren’t there. But in the last 10 years or so, there’s been a real strong push from the producers, from the stakeholders, because they have a lot of competition from international producers — for example apples from Chile and China, etc. — so they need to increase their production efforts, and labor is probably the biggest cost they have. They see labor-saving technology as critical to their survival.

Q: How is the USDA adjusting financially to fund the NRI?

This is a presidential initiative, not a congressional one. There’s no new funding line for this, so every agency has to find some place in their discretionary expenditures and have the appropriate legal authorities to support this program with their regular appropriations. Unfortunately on our end … we have a whole bunch of very specific legal-funding authorities, and those programs are supposed to only be working on certain things. It’s very prescriptive.

There’s really only one significant funding authority for our agency where we have sufficient discretion to use funds for something like [the Agriculture and Food Research Initiative]. It wasn’t increased this year, but at least it wasn’t decreased, which is a good thing.

Q: Do you think NRI funding will survive the current push for austerity on the federal level?

In this administration, I think there’s an expectation, and maybe even a realization, that robotics is one potential driver of economic development going forward in the next 10 to 20 years. It’s a burgeoning industry globally, and especially in Europe and Asia, and we’re going to see more and more economic development surrounding robotics. So if we
can advance that with this research and development program, the NRI, that certainly seems to be a good way to support that.

I think the interest is there and the rationale is reasonably well placed for maintaining this program. The exact levels it will be funded at remains to be seen.

Q: How accessible are these unmanned systems and robotics to smaller mom-and-pop farms, as opposed to larger factory farms? What can be done to close this gap?

Obviously that’s very much a concern for us. We like to have technology that’s scale neutral: It’s accessible from a cross-perspective for small- and medium-size producers as well as large producers. There’s economy at scale associated with these things.

In some cases it’s not just economics; it’s not just cost. It’s other things relative to their operation — their age, who else they’re working with, their comfort level with technology quality tends to improve with newer technology in automation.

Also there’s the opportunity to introduce sensors that can improve the practice; whether it’s harvesting or thinning, it can be improved by the right sensors that humans don’t really have or aren’t very good at. You’re going to see product quality improve.

Q: What does the testing process look like for emerging unmanned systems and robotic technology in agriculture? Are there any standards?

There are some standards, for example safety standards for agriculture equipment. We have suggested in various meetings and asked a couple of people for development of standards for unmanned robotic systems in agriculture. I can’t tell you in what stage that is at right now.

If we’re able to help support the development, we’d like to see them eventually adopted. If jobs that are low skill, low wage, plus dangerous and ergonomically unfriendly.

It is already happening to some extent, because there are new technologies coming in, maybe not so much unmanned systems and robotics, but other technologies that are helping with this. It’s going to have to come with the technology; it’s not going to be one or the other first. It’s going have to be introduced almost concurrently.

Q: What kind of dream technology do you want to see down on the farm in terms of unmanned systems and robotics?

When I sort of go into a dream state about this, what would be nice to see is crop tending robots. That is whatever crop you’re talking about, whether it’s an orchard or tomato field, that there would be a swarm of robots that could fairly continuously move through the field and just monitor and perform opposite stimuli and coordinate among themselves along with the people managing the operation. Things get done, and they can look for pests, detect pests while they’re pulling weeds or cultivating weeds, or whatever the operation might be. There’s just this fairly continuous revisiting of the crop production environment. The operator knows what’s going and what’s being done and feels very comfortable. They know exactly what product quality they’re going to have and what yield they’re going to have at the end of the growing season.

Q: How has the automation of agriculture affected the job market for people working on farms? Are there any new emerging opportunities?

While it eliminates more jobs in the short run, it creates more jobs in the long run. We want to see better jobs and get rid of these other jobs that are low skill, low wage, plus dangerous and ergonomically unfriendly.

While [automation] eliminates more jobs in the short run, it creates more jobs in the long run. We want to see better jobs and get rid of these other jobs that are low skill, low wage, plus dangerous and ergonomically unfriendly.

– Dr. Daniel Schmoldt

in general. That gets into the second piece of accessibility: Do they have the time to use the tech? There’s a learning curve, plus there’s a time consideration.

Q: How does more automation in agriculture affect the quality of the end product?

Robotics and the new automation can actually be friendlier, because instead of human laborers, which get tired, they get fatigued, they get distracted and all sorts of other things, machines do not. The end-product there are safety roadblocks that sort of limit the adoption, we’ve encouraged the appropriate people — the people that set standards and deal with the legal team — to see these are dealt with in a timely fashion.

Q: How does more automation in agriculture affect the quality of the end product?

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When researchers at Carnegie Mellon University wanted to evaluate the usefulness of their ground robot for orchard growers, they did something radical — they put it in the hands of actual orchard growers.

The team leaders of the Comprehensive Automation for Specialty Crops (CASC) program have developed a machine, based on a commercial Toro platform, that can autonomously trundle down orchard rows, allowing human workers atop it to prune, thin fruit, train and tie trees, or harvest.

“For the first time in my career, we developed robots ... and we gave them to Penn State and Washington State, to the [agriculture] extension people,” says Marcel Bergerman, the CASC project manager and a systems scientist with Carnegie Mellon’s Field Robotics Center. “Not to engineers, we gave them to the extension people, and they take these machines to actual orchards, commercial orchards with growers, and they go in and do the experiments themselves.”

Previously, orchard workers would take a ladder, climb it to perform a task, climb back down and move the ladder. “Now this is driving slowly down the row, and instead of literally going up the ladder, down the ladder, and moving the ladder, over and over again. There are some statistics, I don’t know the exact numbers, but about 30 percent of accidents in orchards can be somehow related back to ladders,” says Bergerman.

To avoid that, CASC developed an automated version of Toro’s E-Workman platform, named the Autonomous Prime Mover. They delivered APM systems to agriculture extension programs and growers last year, keeping one in-house for system modifications and testing. The APM has a scissor lift on top of it that can carry two workers, who can control the vehicle if they want but who no longer have to climb up and down ladders.
“It’s an interesting case. It’s autonomous but manned,” says Sanjiv Singh, the project director and a research professor at the Robotics Institute.

CASC has developed two generations of the machines, which have grown a little bit simpler over time. The first version had an iPad interface, but “iPads aren’t meant for readability in sunshine” and they can heat up, even in the winter, Singh says.

“We’ve gone back and done something a little bit lower tech but more sturdy, and it will work in any lighting condition,” he says. The interface now sports an E-ink panel, like a Kindle e-book reader, and has more discrete buttons, a slider bar for speed control and a foot pedal.

“You put it at the beginning of the row, flip the switch, and … you press the foot pedal and the vehicle starts creeping in the row,” Singh says. “When it gets to the end of the row, it detects the open space with a laser and stops automatically. The workers atop the scissors lift use a joystick to drive it to the next row. … It’s an autonomous vehicle that does one thing only.”

That one-trick pony has a good trick, however. CASC loaned the vehicles to the agriculture extension programs at the partner universities, which in turn lent them to orchards. In one case, the extension program also set up a John Henry-style competition between the APM and a man on a ladder.

The video, which was shown at AUVSI’s Unmanned Systems Program Review 2012, showed that the automated platform is capable of making much better time.

**CASC**

The overarching philosophy of the CASC program is to go “from information management to mobility to manipulation,” Bergerman says.

Information is data about crop health and yield, using such things as soil and moisture sensors, automated calipers and counters, and fruit counting and sizing systems, to allow farmers to make better management decisions. Mobility means a vehicle, such as the APM, that allows autonomous mowing and spraying. Manipulation means higher level functions such as pruning, thinning and harvesting.

“Let’s jump forward into the future — 10, 20, 30 years. A robot will go out and do the pruning and the thinning and the harvesting for you,” Bergerman says. “That’s not our focus right now. The focus is how do you augment human workers to make them more productive, more efficient and more safe.”

CASC is funded at $6 million by the U.S. Department of Agriculture Specialty Crop Research Initiative, established by the 2008 farm bill, with matching funds from industry and university partners. Those partners, in addition to Penn State and Washington State, include Oregon State, Purdue, the USDA Agricultural Research Service Appalachian Fruit Research Station, Vision...
Robotics, Toro, DBR Conveyor Concepts, Spensa Technologies and Trimble.

Its initiatives include developing an automated bug trap that can trap and count specific types of insects, an automated tree caliper and counter, a harvest augmentation system, and a scout vehicle that assesses crop load.

The program has included the work of 69 students in its three-year life, including summer students and those who have worked with it for its whole existence.

“One of the reasons the program was created, besides creating new technology, is to educate a new generation of ag engineers,” says Bergerman. “That’s been missing in the U.S. for a long time now.”

End users

Singh and Bergerman attend events such as the recent Mid-Atlantic Fruit and Vegetable Convention in Hershey, Pa., where they spoke with Mission Critical. They use such events to demonstrate their technology and discuss how farmers might use it and how they feel about it.

In the first year, Singh says, the planned equipment tended to be expensive and the reaction was “pretty muted.” Now farmers and growers “have started to get a little more excited about it … because they can actually see connection to their work,” Singh says.

Price is a huge consideration in the agriculture market, he says.

“If you suggest a $5,000 user interface for a military system, it’s not a big deal. No one even asks about that. You couldn’t have a $5,000 control interface for an ag robot; it just would not compute,” he says.

That also means that the machines can’t be made as smart as the orchard growers might like. Singh says some growers have said that the machines couldn’t work for them because they’re not smart enough to negotiate the ends of tree rows, where the ground may slope up or down. Growers tend to use as much land as they can, which leads to irregularity at the ends of the rows.

“Somebody asked me about that today when I was giving my talk: ‘I don’t believe your machines are going to be able to deal with the ends of rows.’ I said you don’t want us to deal with that, because you wouldn’t be able to justify the extra cost associated with that. You’d be better off making your rows slightly shorter and giving the vehicle a little bit more room to turn around in the flat area.”

In other words, “If you’re going to automate orchards, you’re going to have to build them to suit,” he says. “This is kind of the educational process. … We build these machines to spur people to ask questions.”

Brett Davis is editor of Mission Critical.

For More Information:
http://www.cascrop.com
HOW are pruning and fruit thinning like precision agriculture? In tree fruit, pruning has long been considered an art, requiring the skill of a surgeon and the insights of a poet. Fruit thinning is viewed as an excruciatingly tedious and expensive hand process, and/or a spray program relying on hunches and wishful thinking.

Precision ag is the opposite, relying on accurate measurement, statistics, and modern technological tools. More like a robot with a two-year degree in agronomy who doesn't care about the weather or time of day.

Precision ag conjures up images of a very large GPS-equipped tractor dispensing a variable rate application of seed, fertilizer, lime in a very large corn field, or perhaps a GIS-based brightly colored aerial map diagramming soil types and drainage patterns, or a photographic image of relative vegetative vigor generated in an aerial flyover or even via satellite.

It would seem that precision ag, in which we seek to measure and manage variation at the field level, has such tremendous potential for tree fruit, since the cost (and potential return) on our input and management investment per unit area are so much higher than extensive crops like corn, wheat, and cotton.

Additionally, the cost of management inaccuracies or inefficiencies in the early years of orchard establishment are compounded annually, so it would seem even more attractive to understand, characterize, and account for site variability from the get go.

Yet, precision ag remains largely conceptual for tree fruit. Perhaps part of the problem is that precision ag has tended to highlight the use of tools like satellite imagery, information technology, and geospatial analysis, with a particular emphasis on satellite positioning systems like GPS. These tools are of more obvious and immediate application in field crops. In many orchards, for example, the canopy cover prevents reliable connection with satellites necessary for GPS.

If we shift focus, however, to the approach, rather than the tools, it would seem most tree fruit horticulturists are in fact applying the principles of precision ag every day. They have visceral knowledge of their need to measure and manage intra-field variation. In fact, it would be even better if we could manage at the plant to plant, or even the intra-plant level.

Here is where pruning starts to resemble precision ag. And as we finish up pruning in the Pacific Northwest, blessed with a relatively mild winter, we have already completed the first step in precision management. As pomologists have preached for years, crop load management should start early, with pruning. This step defines the framework for subsequent management of vegetative and reproductive growth in the tree. As the industry moves unilaterally from low- to high-density plantings, pruning actually becomes more predictable and less poetic, but it is still done by hand. It’s not an easy job even when conditions are mild, and every year there are fewer workers willing to perform it. It is a practice that cries out for optimization.

**Thinning For Precision**

Mechanical hedging and topping is standard practice in many tree and small fruit crops, as a one-step process or as a setup for subsequent
Moving Toward Automation
Apple growers in Pennsylvania are making their orchards more adaptable to new technology. The good news is, this technology is getting closer to market.

Editor's Note: The cover story of American/Western Fruit Grower's April issue featured growers and researchers in Pennsylvania who are involved in a Penn State University Conservation Innovation Grant (CIG) project to develop growing systems that will allow greater orchard mechanization and labor efficiency in the near future. This month, we highlight some of the technology that is part of this transition to mechanization, and how the state's apple industry responded to changing market trends in order to make this happen. Much of the information for this article comes from a “Specialty Crop Innovations: Progress and Future Directions” report published by Penn State Extension.

UNTIL recently, nearly three-quarters of Pennsylvania's apple crop was destined for the processing market. However, as the industry moves toward more fresh-market production, this transition has required a greater focus on fruit quality and getting full production in a quicker period of time. Increased productivity, however, comes at a cost. High-density orchards require supplemental tree support that adds greatly to their initial investment. Average establishment costs for a high-density block in the Mid-Atlantic region are between $8,000 and $10,000 per acre compared to traditional low-density systems that cost $2,500 to $3,000 per acre to establish. Early and significant yields—a key benefit of high-density production—are critical in achieving maximum economic return and expedited payback in these systems.

The investment is well worth it, however, especially when it comes to future savings in labor. “Transitioning to uniform, high-density orchards will put growers in the best possible position to take advantage of new labor reducing technologies as they are developed,” says Matt Harsh, a fruit and vegetable grower in Smithburg, PA.

A New Orchard Blueprint
While it is a well-known and generally agreed-upon principle that smaller trees require less labor because they require less pruning and minimize ladder use, few high-density training systems were developed with labor efficiency in mind, and fewer still to facilitate the use of labor-saving mechanization. In fact, Jim Schupp, associate professor of pomology at Penn State's Fruit Research and Extension Center, has declared at several industry meetings the past few years that fruit growers need to rethink their planting systems and make them more compatible with the potential benefits that mechanized orchard technology can provide.

A few years ago, tree fruit researchers at a fruit production workshop developed a “blueprint” of a successful intensive apple system (the blueprint includes dwarfing rootstocks and high tree density; quality nursery stock; supported canopies; single rows of tall narrow canopies; a canopy shape that complements natural tree form; minimal pruning; and minimal branching structure). In order to be economically productive, the orchard needs to achieve high light interception without creating dense areas in the canopy. Over time horticulturists found that when an orchard system is entirely within the reach of a person on the ground, one of two bad things happens: Either the canopy is productive but too dense, causing a loss of fruit quality, or the canopy is too small, causing loss of yield. The solution has been to increase canopy volume without condensing the canopy by growing the tree taller, while keeping it narrow and orienting the rows in a north-south direction wherever possible to minimize cross-row shading.

According to Schupp, these narrow fruiting wall systems can provide several advantages:
• The tall narrow tree wall is horticulturally sound, and its biological efficiency surpasses the performance of most existing systems.
• Sunlight: and labor have the same reach. With narrow canopies, you can address both problems of light distribution and platform labor reach simultaneously.
Some growers have built their own platforms and others have used semi-autonomous platforms with harvest assist capabilities from Washington or directly from Europe. In addition, Carnegie Mellon University has automated a model of an Italian platform that is being evaluated by Penn State. Through the “Comprehensive Automation for Specialty Crops” (SCRi) project, Carnegie Mellon engineers led by Dr. Sanjiv Singh have also added sensor technology to these platforms.

In tandem with mobile platforms, the use of harvest-assist technology is also being addressed. Knowing that sensitive fruit handling has long been a stumbling block, Carnegie Mellon and Penn State once again teamed up to evaluate bin filler prototypes. During

Trial Technology

Trials with an orchard platform prototype were conducted in 24 Pennsylvania orchard blocks during 2006 to 2007. Tree architectures included peaches trained to perpendicular V and apples trained to vertical axis. The purpose of taking the orchard platform to as many orchards as possible was two-fold — the research team could evaluate platform efficacy with various modifications of tree training systems, and growers would have the opportunity to assess where tree training and plant spacing adjustments should be made for improved adaptation to automation. An added benefit of commercial orchard trials was that growers and employees provided valuable feedback on possible future directions for team research.

Worker productivity with the moveable platform compared to ladders increased by an average of 35% for peach thinning and pruning and 50% for peach harvest and apple thinning, tree training, or pruning. Task times per acre with ladders ranged from 11 hours for tree tying and pinching to 90 hours for apple thinning, and with the orchard platform ranged from six hours for tree tying and pinching to 51 hours for apple thinning. The platform was more efficient than ladders for all tasks.

CHECK OUT the Comprehensive Automation for Specialty Crops website (www.cascrop.com) for more background on mobile platforms and harvest-assist technology. The “What’s New” section includes videos of autonomous harvester trials in Washington (part of a multi-state trialing system) as well as a vacuum assist harvester.

For more information on innovative thinning technologies, go to www.abe.psu.edu/SCRI. The latest video update highlights automated positioning of the Darwin string thinner, which is being evaluated as part of another multi-state project.

Aside from videos, each of these sites has updated reports on the latest research from across the country.
Purdue's Emerging Innovations Fund invests in two startups

March 20, 2012

WEST LAFAYETTE, Ind. - Officials of an evergreen fund created to help commercialize new technologies announced $100,000 of investments in an information technology startup and a life-science startup, both based in the Purdue Research Park of West Lafayette.

Spensa Technologies Inc. received $80,000, and Tymora Analytical Operations LLC received $20,000 from the Emerging Innovations Fund, which helps move research discoveries from Purdue University to the market. The fund was established in 2008 as a partnership between the Purdue Research Foundation and Purdue University.

"The Emerging Innovations Fund strengthens early-stage companies that have licensed technologies through the Purdue Office of Technology Commercialization or are based in the Purdue Research Park network," said Joseph B. Hornett, senior vice president, treasurer and COO of the Purdue Research Foundation. "As Purdue-discovered innovations reach the market, they benefit the public, strengthen the state's economy and grow Purdue's reputation as a leader in commercializing technology."

Richard Cosier, the Avrum and Joyce Gray Director of the Burton D. Morgan Center for Entrepreneurship, said students from Purdue University's Krannert School of Management participated in the due diligence process to select recipients.

"During the fall 2011 semester, the team that performed due diligence on potential investments from the Emerging Innovations Funds consisted of two Krannert MBA students, two Krannert senior undergraduate students and a Krannert MBA student adviser," he said. "Students who participated for course credit enrolled in the Student Managed Venture Fund."

"The Purdue Office of Technology Commercialization worked closely with Krannert School of Management officials, faculty researchers and entrepreneurs to find discoveries that are in the commercialization process and could best benefit from the Emerging Innovations Fund," said Elizabeth Hart-Wells, assistant vice president and director of the Purdue Office of Technology Commercialization. "Spensa Technologies and Tymora Analytical are outstanding examples of Purdue faculty researchers who have patented Purdue technologies and are moving important products to the public in an expedient manner."

Spensa Technologies is commercializing the Z-Trap, which detects target insects captured by the trap and sends the data wirelessly to the grower's mobile phone or computer. Knowing the types of pests can help inform pesticide use to be more selective and specific, favorably affecting costs spent on chemical usage.

"The Z-Traps automate the monitoring of insect populations in agricultural fields and provides unprecedented real-time, accurate insect population data," said Johnny Park, president and CEO. "Using more current data will help growers and pest-control advisers make timely and effective pest management decisions, which can help reduce insecticide use on food crops, save money for the growers and emit fewer chemicals into the environment."

Park said the award will help Spensa Technologies manufacture 75 pre-production models of the Z-Trap and carry out large-scale field experiments and evaluations during the 2012 growing season.

Tymora Analytical Operations' products are intended to make cancer research and drug discovery more efficient and...
Anton Iliuk, president and chief technology officer, said the end user implements the products in the laboratory to achieve reliable results during the life-science research and discovery stages.

"The award will help us with the initial sales and marketing steps of our first commercialized product, called PolyMAC," he said. "It will help us bring our next product, pIMAGO, to the market next year. It also will give us good leverage to obtain subsequent investments, including non-dilutive investments."

**About the Emerging Innovations Fund**

In 2008 Purdue Research Foundation introduced the Emerging Innovations Fund (http://otc-prf.org/emerging-innovations-fund), an integrated approach to research innovation, development and commercialization. The Emerging Innovations Fund is a self-sustaining initiative that brings together ideas, management and money to accelerate the commercialization of early stage technologies in the Purdue community.

About Spensa Technologies Inc.

Spensa's mission is to design, develop and deliver novel technologies for the agricultural industry that will reduce reliance on manual labor, foster eco-friendly farming, and enhance crop production efficiency. Our technologies leverage our world-leading expertise in wireless sensor networks, robotics and computer vision.

**About Tymora Analytical Operations LLC**

Tymora Analytical Operations was established in 2010 to provide new nanotechnology-based products to serve the R&D market in the life sciences. Tymora has developed a nanoscale platform technology - with PolyMAC and pIMAGO as the lead products - for unmet needs in analysis of protein phosphorylation that relates to the onset of numerous diseases, most noticeably cancer.

**About Purdue Research Foundation**

Purdue Research Foundation (http://www.prf.org) is a private, nonprofit foundation created to advance the mission of Purdue University. The foundation accepts gifts; administers trusts; funds research, scholarships and grants; acquires property; and negotiates research contracts on behalf of Purdue. In the 1990s, the foundation was charged with helping the university in the realm of economic development. The Purdue Research Foundation oversees the Purdue Research Park, which is the largest university-affiliated business incubator in the country. In addition to the Purdue Research Park of West Lafayette, the foundation has established technology parks in other locations around Indiana including Indianapolis, Merrillville and New Albany.

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A whole 'nother APM -- robofarmer!

Posted by Chris Anderson on May 8, 2012 at 11:00pm  View Blog

Nothing to do with UAVs (and the "APM" thing is just a coincidence), but I thought I'd pass it along anyway as a great example of human/robot interaction. The autonomous farm vehicle does the driving while the worker does the cutting.

(via Missy Cummings)
Spensa Technologies Inc. of West Lafayette, Ind., has launched a new online application that allows growers and consultants to electronically track insects in their fields to improve pest management.

Users visit MyTraps.com and enter insect data and pesticide records on the secure website using a Web browser or smart phone, according to a news release.

Once the information is input, the program will create insect population graphs.

The program also provides satellite field images over which the insect data is placed.

Not only can insect data from just about any crop be entered, but the program will store the information so users can view trends or field histories.

"Most of the time, data is collected on sheets of paper by walking around the fields and checking insect traps," Johnny Park, president and chief executive officer of Spensa, said in the release. "MyTraps.com provides tools to make the insect data collection easier and to make better pest management decisions."

Park also is a research assistant professor of electrical and computer engineering at Purdue University in West Lafayette.

MyTraps.com is available by subscription.

Spensa also is developing the electronic Z-Trap, which automatically detects the number of target insects caught and transmits the data to computers or cell phones.

This season, the company will have 75 prototype traps in large-scale field trials.

The traps will be used to collect data on codling moths, Oriental fruit moths and leafrollers in apple orchards.

The firm hopes to launch the traps commercially in 2013, according to the release.

It also plans to develop the traps to detect other types of insect pests.

Read related article in The Grower: Iffy labor supply drives development of labor-saving equipment

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Iffy labor supply drives development of labor-saving equipment

01/20/2012

By Renee Stern, Contributing Editor

New labor-saving equipment for treefruit and lettuce growers should reach the market in the next two years.

The latest push to mechanize agricultural tasks reliant on a chancy labor supply includes automated insect traps and machines to thin lettuce and simplify apple harvesting. The devices are undergoing modifications based on promising field trials.

**Automated orchard traps**

Much of orchard scouting currently relies on deploying and regularly inspecting mainly delta traps baited with pheromone lures for specific insect pests—a time-consuming process, particularly with widely scattered blocks. New automated traps could speed that.

The traps are expected to undergo largescale field tests this season for a potential market introduction the following year, says Johnny Park, research assistant professor in computer engineering at Purdue University in West Lafayette, Ind.

The Z-traps—named for the zap delivered to insects that venture inside—identify species through the bioimpedance signal emitted when a specimen is hit, combined with the time of day it’s collected.

Sensors can distinguish between non-target insects and codling moth, Oriental fruit moth and obliquebanded leafroller, and eventually should allow a single trap to use lures for all three.

Using one trap for multiple pests not only simplifies scouting but also boosts costeffectiveness, says Vince Jones, entomology professor at Washington State University’s Wenatchee research center.

“Obviously the technology is not going to be cheap,” says Larry Hull, emeritus professor of entomology at Penn State University’s Biglerville research center. But while manual traps might cost less up front, automated traps pull ahead through overall labor reductions.

An electronic network links each trap in a block, and their GPS-identified data is uploaded regularly to a secure website.

Growers can log in from anywhere using a computer or smartphone, or set up alerts when trap catches reach threshold levels.

“So much of orchard management depends on information that’s time sensitive,” Jones says.

Park also runs Spensa Technologies Inc., a spinoff company bringing the Z-traps to market. The company will release myTraps, an online tool to manage trap data, later this year.

The subscription-based application produces spatial and temporal maps from data from current delta traps or the new Z-traps, he says. Another function will allow growers to store their pesticide application records.

The Z-traps are back in the labs to improve power usage and strengthen wireless and detection systems.

Current batteries last two weeks; swapping in replacements that often cuts into labor savings, Jones
says. The goal is batteries that last through the growing season.

Tests show the traps perform at least as well as standard delta traps, Hull says.

Deployment is similar, with the caveat that the Z-traps' electronics add weight that requires sturdier branches as anchors.

Future developments could add more detectable insects, he says, from natural enemies to a newer orchard threat, brown marmorated stink bug.

**Labor-saving lettuce thinning**

Labor concerns also drive development of thinning and harvesting machines. Even before the most recent harvest-worker shortages around the country, Arizona's lettuce industry had pinpointed an aging workforce with few replacements in sight, says Kurt Nolte, director of the University of Arizona's Yuma Agricultural Center.

"The future is mechanization," he says.

A lettuce thinning machine developed in part by Mark Siemens, associate professor and specialty crops mechanization specialist at the Yuma facility, makes better use of fewer field workers.

The most recent tests of a 42-inch-bed model thinned 2 acres of lettuce per hour, Siemens says. By comparison, one person can hand-thin an acre in eight hours.

A model twice as wide is in the works for growers planting 84-inch beds, Nolte says.

The machine's current 1 1/2 mph speed is acceptable for commercial conditions, Siemens says. But he hopes to improve that speed to 2 or even 3 mph in the coming year.

The tractor-towed machine analyzes on-the-go images and determines, based on preprogrammed spacing specifications, which plants to thin with precisely directed herbicidal sprays. The entire operation occurs in one pass through the field, Siemens says.

Computer speed limits how fast the machine can traverse the field. Beyond that, a limited number of herbicides registered for lettuce is the remaining concern.

Sulfuric acid is highly effective and inexpensive, but would need regulatory approval for such a use, he says.

Thinning with herbicidal sprays rather than a mechanical knife reduces the machine's moving parts and minimizes soil disturbance that would encourage weed growth, Nolte says.

The university has submitted a patent application, aiming to license the technology to manufacturers, Siemens says.

**Vacuums help apple pickers**

Several companies are developing harvestassist machines for apples and other tree fruit. DBR Conveyor Concepts in Conklin, Mich., is about a year away from bringing a tractor-pulled vacuum harvester to market, says owner Phil Brown.

Additional modifications are planned ahead of a new round of tests in California canning peaches and Washington apples.

"I'm excited by the opportunity to employ a machine like this," says Brent Milne, assistant orchard manager at McDougall & Sons Inc. in Wenatchee. Last year's field trials included work in the company's orchards.
Vacuum hoses connect to a rotating bin filler, all set up between hydraulic platforms that position harvest workers at the canopy. Alternately, platform-based workers can concentrate on the top branches with pickers on the ground harvesting the lower half, eliminating ladder work entirely.

The machine offers opportunities to people unable to climb ladders or hoist picking bags day after day. “That takes the pressure off,” Milne says. “The machine does most of the work of transporting the fruit and the worker is only taking it off the tree.”

A five-week Washington field trial highlighted ways to reduce bruising, the key remaining hurdle, says Karen Lewis, WSU tree-fruit specialist in Ephrata. Modifications include adjusting the fruit decelerator and bin filler, as well as training workers to place apples in the vacuum hose one at a time.

Large and small apples are sucked through the hose at different rates, potentially allowing them to catch up to each other with a bruise-producing impact, Brown says.

Inconsistently sized fruit creates the most problems.

Foam pads the hoses and decelerator. In the Washington tests, sunburn protectants initially clogged the decelerator and reduced its fruit-slowing capacity, Lewis said, but field modifications solved that problem.

A four-hose system can handle 16 apples per second—faster than pickers can work, Brown says. In ideal conditions, the machine can fill a box, offload it and take on a new container in less than 10 minutes. Adding lights would extend the harvest day.

That speed is “absolutely within industry standards for efficiency,” Lewis says.

“A uniform canopy and crop load, with easily accessible fruit, is the key to optimizing almost any level of mechanization,” she says.

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June 6, 2012

By Brian Sparks

It was just a couple years ago that Michigan apple growers Mike Rasch and Chuck Dietrich, along with equipment guru Phil Brown of Phil Brown Welding in Conklin, MI, got together to form DBR Conveyor Concepts, LLC. The three had been working together on the development of an apple harvesting prototype that uses a vacuum system to pull picked fruit into bins on a trailer. Their goal was to create a model that would maximize labor efficiency, minimize fruit bruising, and be adaptable to different equipment. DBR would serve as a way to develop, manufacture, and market the machine, bringing the expertise of all three men into the mix.

2011 marked the first full year of field testing, and it was not limited to Michigan. Different models of the prototype were sent to Pennsylvania and Washington for evaluation, giving university researchers and growers the chance to trial the device in their own unique regions.

“We tested the DBR machine in Washington last season for five weeks,” says Karen Lewis, a tree fruit Extension horticulturist at Washington State University. “We mostly spent time getting the machine up to our thresholds. We worked in several architectures, varieties, and harvest scenarios.”

While harvest efficiency improved by about 20% compared to ladders, it was clear that some modifications were still necessary to reduce bruising and limit the number of culls.

Making Adjustments

This past winter, the DBR team set to work making these necessary modifications. “We have the vacuum and bruising pretty much conquered, so now we’re making a bunch of changes to help efficiency and improve bin leveling,” says Brown.

Leveling was perhaps the biggest focus in the modifications. “We added a hydraulic side level to keep the platform more level to the tree, and keep the bin level in all four directions, so a grower can fill the bin even or all the way up,” says Brown. “We also designed a feature on the bin filler that allows it to fill the box more level if someone is picking from just one side of the machine, like an outside row,” notes Rasch, who also points out the importance of recognizing the differences between Michigan and Washington in orchard design and variety mix. “They have solid variety plantings out west, and our varieties are interplanted, sometimes row by row.”

What’s On Tap For 2012

As of early June, these renovated models were scheduled to be shipped back out across the country for further review for this coming season. Here’s a brief look at what researchers are looking for:

• Pennsylvania: “We are currently looking more closely at the tube flow characteristics of the vacuum-driven harvesting unit,” says Paul Heinemann, a professor in Penn State University’s Department of Agricultural and Biological Engineering. “This includes power requirements to create
sufficient negative pressure to move fruit of different sizes through the tubes, gravity-assist, and velocities of the fruit (and its effect on impact potential). Our goal is to optimize the power requirement to improve the efficiency of the unit, using only enough energy as needed.”

Heinemann notes that the extent of future testing and development will depend on their success with Specialty Crop Research Initiative funding; however, “DBR continues to work on development regardless of the funding situation.”

• California/Washington: On its trip westward, the DBR will first land in California, where it will undergo five weeks of testing during peach and pear harvest. From there, it will go back up to Washington.

“We hope that with the modifications we can focus on operation efficiencies,” says Lewis. “We will focus on tops of canopies and run two shifts per day, depending on the variety and the weather.”

• Michigan: While the DBR team will be using a slightly modified version from the one in Washington, their goal is to roll both versions together into one model, says Rasch.

The one factor that could have an effect on trial results in Michigan this year is weather. A warm spring, followed by frosts in April and early May, have contributed to spotty crop conditions. “We’re on board with the Michigan Apple Committee and researchers to do trials for the fall fruit season in four fruit areas,” says Rasch. “But we don’t know what the crop will be in those regions. We’re still gearing up, and will go where we have to. At the very least, with the yield down, it could affect efficiency.” Rasch points out, however, that the wide range of data available from Washington could make up for this.

Landmark Technology

So how close is the DBR model to being available for commercial use? “We hope it will be ready for 2013,” says Brown. “But we’ll likely make a few more changes along the way.”

Rasch says the partnerships between researchers, engineers, and growers have gone a long way to bring the DBR system closer to fruition. “We’re very grateful for that.”

One of the most optimistic individuals involved in the testing is Phil Schwallier, district horticultural marketing agent at Michigan State University. “I believe this is a landmark technology change in the fruit industry,” says Schwallier. “It is one of the first machines that will actually machine assist apple harvest and could replace the long traditional hand-picked bag system.”

Not Just For Harvest

Perhaps the most significant benefit of the DBR model, according to Mike Rasch, is that it will have year-round application. The blower and vacuum system can be easily removed so that the platform can be freed up for other purposes, from thinning to pruning. “We wanted a way to help growers use the tractors they already own to carry it,” says Rasch.

For More Information

Want to keep up with new developments with the DBR as well as other orchard technology? Head to www.cascrop.com, the website for the Comprehensive Automation for Specialty Crops program. You can watch videos of new equipment in action, learn more about the expert teams involved in
research trials, and get a first-hand look at what’s being talked about across the country.

Brian Sparks is editor of American Fruit Grower, a Meister Media Worldwide publication.
Robotic Assistance Becoming a Reality for Growers

by Sally Colby

Growers might joke about how much time they'd save if only they could push some buttons and send a vehicle to the orchard and let it perform critical but monotonous chores on autopilot, or at least have the vehicle self-steer while workers on a platform perform tasks such as thinning, tying and picking.

Thanks to collaboration among fruit growers, extension personnel, researchers and an energetic and creative robotics team from Carnegie Mellon University, that dream is becoming reality. Although the project is still under way, progress is being made with the autonomous prime mover, or APM.

“We hope this machine will be useful to growers to increase production efficiency and decrease labor costs,” said Dr. Marcel Bergerman, systems scientist at the Field Robotics Center at Carnegie Mellon University in Pittsburgh, Pa. Bergerman is the project manager for the Comprehensive Automation for Specialty Crops (CASC) project, funded by the USDA Specialty Crop Research Initiative established by the 2008 Farm Bill. “The machine can be used for many tasks throughout the year,” he said. “There’s no driver, so that’s a cost savings. You can use the machine to go down the row for pruning, thinning, training and even for harvesting. You can attach a mower or a sprayer to the back of the machine and it works for you while you’re taking care of other more strategic aspects of fruit production.”

Right now, Bergerman and his team are in year three of the four-year project. “In year one, we worked on proof of concept,” he said. “We were only worried about having it go down the road and come back. During year two, we concentrated on robustness. We operated on different types of terrain, and it was hand-tuned by our engineers every time we went out. Now we are trying to see if it’s actually useable by growers.”

Bergerman says that during the testing phase, APMs were placed in Washington state and in Pennsylvania for extension...
educators and growers to use, test and break so that the team can uncover and solve problems. “It’s that cycle of experimentation that will eventually make it commercially available and useful to growers,” said Bergeeman.

Brad Hamner, senior research programmer at Carnegie Mellon, developed the programming for the APM. “There’s a laser range finder on the vehicle that sends a laser beam that hits the tree and comes back,” he explained. “By measuring how long that beam is, we can get a distance to the tree. The laser beam sweeps around so the vehicle can ‘see’ all the trees around it. From there it’s a pretty simple matter—we know we’re looking for two parallel lines of trees. The computer finds those two lines, and tells the vehicle to drive.”

The computer associated with the APM runs a Web page that can be accessed by any device that has a Web browser. Hamner mounted an iPad on top of the vehicle, and using the touch pad, the operator can control the APM to drive up to 2 mph. A simple slider control directs the vehicle to drive straight down the middle of the row or to move closer to one row.

Hamner noted that although the technology is fairly simple, the challenge has been in adapting the APM to operate in a variety of canopies, from newly planted trees to mature trees in various planting systems. The vehicle performs best in vertical axis or fruiting wall orchards. In tests at Penn State University’s Fruit Research and Extension Center (FREC) in Biglerville, Pa., the vehicle was operated as a scaffold on which workers could stand to perform tree maintenance tasks such as training, thinning and pruning. The team is hopeful that the APM can be adapted for use during harvest.

The lead institution for the project is Carnegie Mellon University, in collaboration with Oregon State University, Penn State University, Purdue University, Washington State University and the USDA/ARS.

“There are quite a few growers, researchers, extension personnel and commercial partners as well as student interns who have helped with the project,” said Dr. Tara Baugher, extension educator at FREC. Baugher added that the Biglerville unit has been dubbed “Allegheny,” while a sister machine in Washington state, known as “Cascade,” is being introduced to growers by extension educator Karen Lewis.

The author is a new contributor and freelance writer who farms and raises Great Pyrenees in south-central Pennsylvania. Comment or question? Visit www.farmingforumsite.com and join in the discussions.

The APM can be programmed to move at various speeds so that workers on a platform can safely perform tasks.
Phil Brown, owner of Phil Brown Welding, an orchard implement company in Conklin, Mich., recently demonstrated the latest version of his apple-harvesting machine to growers in Michigan and Washington state.

The core concept of the machine is to eliminate extra labor from the harvesting process. The idea is that a worker picks apples from either scaffolding or walking alongside the machine, then places the apples into tubes where air pulls them into a bin. The trick, according to Brown, is to get the apple to the bin without bruising it.

That is where Phil Schwallier, a Michigan State University Extension educator, joined the project. Schwallier ran bruising trials on the newest machine.

“We ran trials on McIntosh, a very soft variety, for bruising and counted every scuff,” he said. “The average was 13 percent bruising or scuffs. Each apple would still pass U.S. extra fancy grade. Basically, there was no bruising to speak of. This is a landmark change in technology. I think this will have a major impact on apple production in North America.”

To achieve the low bruise rate, Brown worked on slowing the apple down as it passed along the tube. In addition, the apple lands on several well-padded, rotating blades that gently roll it into the bin one at a time, he said.
"The key is getting the velocity to change according to apple size," Brown said. "We needed to keep single apples coming into the bin. It is the apple-to-apple contact that creates bruising."

When the bin is full, an electronic eye notifies the operator, who disengages the bin. The full bin slides under the bin trailer and another empty bin lowers into place on the rack.

"It takes less than a minute or so to swap out a bin," Brown said.

Some other key changes to the latest version include being driven off a tractor PTO.

"You need a 65- or 70-horsepower tractor at least," said Mike Rasch, a Conklin, Mich., grower who worked with Brown on the design. "If it is low geared or runs a hydrostatic transmission, you can just run along, picking as you go. The blower motor is also not as powerful as it was before, but it is now quieter and cheaper."

Making the new machine quieter was a goal for Brown. The machine has a large muffler system that keeps decibel levels down and allows workers to communicate with each other, he said. Other features are a series of gauges that tell the operator if the machine is running efficiently or if the screen used to catch leaves and debris needs to be cleaned.

There are significant labor savings, Brown said. The harvester eliminates ladders, bags and walking to and from the bin, so time is saved and fewer workers are needed to harvest the crop. The platforms on each side of the machine raise and lower 4 feet, and swing out 2 feet to accommodate different trees and rows. The harvester also can be used for pruning and other tree maintenance.

Brown has been refining the machine for several years. He plans on selling models next year, he said. He hopes the cost to be $75,000 to $100,000, depending on how it is configured.

"This machine will change how we harvest apples and have as big of an impact as cold storage, CA storage and Smartfresh did," he said. "Now, we have a harvesting machine that works."

Click here to watch the Apple Harvester in action.

By Derek Sigler, Associate Editor

Originally posted Friday, Nov. 4, 2011
New orchard technologies are coming

Tree fruit growers saw a glimpse of what’s soon coming in the way of new orchard technologies during a field day hosted by Washington State University.

MELISSA HANSEN

Several new technologies for orchards—from driverless platforms and harvest-assist machines to laser tree counters for nurseries to traps that send insect counts to orchardists—are moving from the ‘what if’ to the ‘when’ category. A recent “show and tell” day at Washington State University’s Sunrise Research Orchard near Wenatchee gave growers a view of technologies that are near commercialization.

Sanjiv Singh, part of a research team at Carnegie Mellon that’s working on various projects for the tree fruit industry, calls the autonomous platform the ‘Swiss army knife’ of orchard platforms, because it can perform a variety of orchard tasks, from thinning to spraying to mowing. The driverless, electric-run vehicle looks like a sturdy golf cart, but can navigate down an orchard row, turn at the end and go up and down rows—without the need for a driver. Laser scanners mounted on the front of the vehicle provide a two-dimensional map of the trees to steer the vehicle.

Speeds can be set for slow mode, 0.5 to 1 mile per hour, a speed used in tasks like thinning, or a faster mode, which goes 3 to 5 mph and would be used for chores like mowing. Workers on the platform control the vehicle speed and stopping, as well as movement up or down. By attaching a bin trailer to the vehicle, workers on the ground can perform tasks like color picking while controlling movement and speed of the bin trailer with a remote control.

The Carnegie Mellon research group is also working to develop a voice-controlled autonomous platform and vehicle.

Nursery tree counter

Also near commercialization is a laser-based sensor mounted
on the front of an all-terrain vehicle to count trees, said Marcel Bergerman of Carnegie Mellon. The laser tree counter, which Bergerman demonstrated by driving down an orchard row at about five miles per hour, was 100 percent accurate in its count. The row had 123 trees and three wooden posts, counted as 126 by the laser.

Nurseries have been anxious for an accurate, automated way to count and measure the caliper of seedling trees growing in the field, said C & O Nursery’s Gary Snyder while watching the counter demonstration. “If we could know when the trees are still in the ground, what size and number we have, then we can share inventories with the grower sooner.”

Accuracy of the tree counter is about 98 percent, though further work is needed in measuring tree diameter, Bergerman said. “The caliper measurement works well when trees are not staked. But in staked trees, every once in awhile, a stake is added to the diameter of a tree,” he said, adding that caliper measurement is accurate, down to an eighth of an inch, but they need to be able to account for the stakes.

Bergerman envisions that the interface for the laser counting device, which currently is connected to a laptop, would be accessible on a smart phone, like an iPhone or Android, making it user friendly. Though Carnegie Mellon is looking for a partner to commercialize the technology, the current setup has already been used in the real world to provide an accurate tree count as part of an insurance claim in Oregon.

The technology demonstrations are part of a national research project called Comprehensive Automation for Specialty Crops. Partnering institutions include the universities of Carnegie Mellon, Oregon State, Pennsylvania State, Purdue, Washington State; USDA’s Appalachian Fruit Research Station; and the private companies of Vision Robotics, Toro, DBR Conveyor Concepts, and Trimble. The $12 million project is funded by the U.S. Department of Agriculture’s Specialty Crop Research Initiative, with matching funds from industry and university partners. It’s a collaborative effort involving researchers, engineers, manufacturers, and tree fruit growers from across the nation.

*Look for in-depth stories about the apple harvest machine and electronic insect trap in the November issue of Good Fruit Grower.*
Latest orchard automation demonstrated

Updated: Thursday, September 29, 2011 12:50 PM

Universities share fruits of $12 million in research funding

By DAN WHEAT

Capital Press

ROCK ISLAND, Wash. -- Tree fruit growers got a peek into what researchers say is the future of orchard automation at the Washington State University Sunrise Research Orchard.

The latest developments in automated apple harvest, a self-propelled orchard work platform, a digital pest trap and an electronic tree counter were demonstrated by public and private researchers on Sept. 23.

The $12 million Comprehensive Automation Specialty Crops research project is part of the 2008 Farm Bill and dedicated to the $18 billion U.S. deciduous tree fruit industry and the $17 billion U.S. nursery and landscape industry.

Participating universities are: WSU, Oregon State, Carnegie Mellon, Purdue and Pennsylvania State.

Phil Brown, owner of DBR Conveyor Concepts, Conklin, Mich., operated his tractor-pulled apple harvester that eliminates picker bags and ladders. Pickers on the ground and on platforms that can be elevated, lowered and moved in and out can place fruit into vacuum tubes that suck the fruit into a bin. Four empty bins ride on a trailer behind the harvester. They slide into place on the machine for filling and, when full, are deposited on the ground for hauling by a separate tractor.

The goal is four pickers using the machine filling 80 bins a day, double the usual 40 bins a day with bags and ladders, Brown said. It may reduce the need for pickers by a third, he said.

Workers also can use the machine instead of ladders to thin fruit, prune trees, string wire and tie tops of young trees, Brown said.

Depending on testing this fall, Brown hopes to sell the harvester for less than $100,000 apiece next year to growers in Michigan, Washington and Pennsylvania.

After watching a demonstration of an electronic tree counter, Gary Snyder, co-owner of C&O Nursery, Wenatchee, said he's eager for them to save time and money and get greater accuracy on numbers and size of trees. Employees use hand-held counters right now, he said.

Marcel Bergerman, a Carnegie Mellon scientist, demonstrated a laser device mounted on an ATV that can count trees at 2 to 5 mph with 98 percent accuracy. It counts trees as small as one-eighth-inch diameter and can transmit data to a smartphone. It can count trees from a tractor while the tractor is being used to mow or do other chores, he said. A caliper to record the size of tree trunks still needs work as it now counts stakes, too, he said.

Professors Vince Jones, of WSU, and Johnny Parks, of Purdue, showed a digital trap that can detect and count two targeted insects and transmit real-time data, saving time visiting traps and counting insects. Depending on testing next year, it could be available in 2013, they said.

A driverless vehicle for mowing, spraying, pruning, thinning and other work was demonstrated.

"The exciting thing is that four years after this project started, we're seeing products nearing commercialization that will make a real difference in a grower's life," said Jim McFerson, manager of the Washington Tree Fruit Research Commission in Wenatchee.
A team of scientists has demonstrated that it's possible for a vehicle to drive itself back and forth between rows of trees in an orchard. The next steps are to make it easier for growers to control the equipment and to convince them that this is not science fiction, but something they will find useful in their own orchards to increase their efficiency and reduce costs.

The scientists, led by Dr. Sanjiv Singh at Carnegie Mellon University’s Robotics Institute in Pennsylvania, began two years ago to develop what the university refers to as an “autonomous prime mover” as part of a larger, multistate research effort on Comprehensive Automation for Specialty Crops.

Carnegie Mellon has developed autonomous equipment in the past, but primarily for the U.S. Department of Defense and the National Aeronautics and Space Administration. Singh said the goal for the first year of the project was to study the feasibility of using autonomous equipment in specialty agriculture, recognizing cost considerations.

The scientists started out by converting a Toro two-seater utility vehicle into an autonomous electric system. They recognized that they couldn't depend on a Global Positioning System to guide the vehicle between tree rows because highly accurate GPS systems are expensive, and reception under dense canopies is poor. To achieve the same accuracy as a high-end GPS system and still make the vehicle economically feasible, they used laser sensors that can sense the distance of the vehicle to the trees. Not only can the vehicle drive between rows of trees and turn at the end of the rows, but in wide rows it can be directed to drive closer to one side or the other.

In the first year, the team logged a total of 120 kilometers (75 miles) of autonomous operation, exceeding the goal of 100 kilometers. Having proven the feasibility in the first year, the scientists focused last year on making the system robust enough to work in orchards or vineyards that might have uneven terrain, dense or light canopies, and extreme temperatures. It was tested on rolling hills at the Fruit Research and Extension center in Hedgesville, Pennsylvania, as well as on slopes and flat ground in Washington State. On flat ground, the laser beams can sense up to 30 meters (100 feet) ahead, but on hilly terrain, they sense the ground in front.

The goal for the second year was to have the vehicle drive at least 100 kilometers, but only runs of at least 10 kilometers at a time counted. That meant it had to operate continuously for hours at a time, navigating numerous trees. Singh said this was accomplished, although there were real-life challenges to address, such as dust clouds during which the lasers picked up reflections from the dust and confused the software.

The term “autonomous prime mover” is a concept, rather than a specific vehicle, Singh said. During the early development phase, they’ve been using the Toro utility vehicle, but last year they used the same navigation concept with an orchard platform from Italy that they converted from a manual motorized vehicle to driverless.

The team just began the third year of the project with the goal of making the autonomous prime mover easier for growers and farm employees to operate. It will have a graphical user interface (somewhat like an iPhone or iPad) so that its operation is more intuitive. The idea is that the user would simply command the vehicle to start at one end of the block and execute a certain task—spray herbicide, for example—and off it would go, and then return when it was done.

This year, the team hopes to have the autonomous prime mover log 100 kilometers of autonomous travel when operated by people other than robotics engineers. The system will be simplified and rebuilt without the research instruments that are currently used to monitor its performance. “We’ll know how well it does by watching it,” Singh said. “It will look simpler, and be simpler and more robust and easier to use.”

Modes of operation

Singh said an autonomous vehicle should be able to serve a variety of purposes. His team has identified four modes of operation:

- **Transport mode**: This is when someone drives it manually from the shed to the orchard block where it’s needed, for example.
- **Mule mode**: People load the vehicle and it drives itself to some other location—perhaps the end of the row—where it is unloaded and then it returns. It could also be used as a “bin dog,” where it follows a person on foot wherever they go.
- **Pace mode**: The vehicle drives up and down rows spraying or mowing without people on board.
- **Scaffold mode**: The vehicle has someone on board working on the crop as it drives slowly down the row.

This year, Karen Lewis, Washington State University Extension educator in Washington's Columbia Basin, and Dr. Tara Baugher, with Pennsylvania State Cooperative Extension in Adams County, will both test driverless utility vehicles.

Lewis said she is using a two-person platform with electric scissor lift installed on the back of the vehicle and will test it for all types of orchard work except harvest. Growers are interested in orchard equipment that is modular and multipurpose, she said, and the two-seater utility vehicle is useful because it can carry two people and a lot of gear. “I think we’re going to see more use of these vehicles,” she said.

Singh said the final year of the project is likely to focus on the economics of the autonomous prime mover, and growers still need to be convinced of the utility of driverless equipment.

Growers who have seen the driverless utility vehicle demonstrated at field days have described it in such terms as “beyond amazing,” but they probably don’t fully appreciate yet what it could do for them on their farms, he said.

The Comprehensive Automation for Specialty Crops project is funded through the U.S. Department of Agriculture’s Specialty Crop Research Initiative.
Scientists have developed a device to automatically count nursery trees in the field.

by Geraldine Warner

Robotics scientists at Carnegie Mellon University in Pennsylvania set out to develop a device to automatically measure the caliper of nursery trees in the field, but found that a simple tree counter would be more useful for the tree fruit industry.

Dr. Sanjiv Singh and colleagues began to develop the tree caliper calculator with shade tree nurseries in mind. The difference in value between large- and small-caliper trees can be significant. The device would be attached to a vehicle and would assess tree size as it moved down the nursery rows.

The project is part of a major research project on Comprehensive Automation for Specialty Crops.

When the researchers discussed the concept with tree fruit nurseries, however, they found that being able to automatically count the number of trees would be more important than being able to measure the caliper in the field.

Singh said developing a counter was much easier than figuring out how to measure the caliper. He and his colleagues first tried an ultralow-cost approach using an off-the-shelf infrared diode that cost about $25. However, the infrared was susceptible to interference.

They then purchased a commercial, off-the-shelf sensor in a sealed unit that cost between $300 and $400 and developed the electronics and software to process the data so the results could be viewed on a laptop computer.

Inventory

Paul Tvergyak, marketing director with Cameron Nursery in Eltopia, Washington, said tree fruit nurseries sell trees by caliper, but they could benefit most from a fast method of accurately measuring caliper and bar-coding the trees after harvest, rather than in the field, to provide an accurate inventory of what’s in storage.

In terms of monitoring in the field, a tree counting device would be the most useful initially because nurseries count trees several times between planting and harvesting for inventory control, he said.

“Counting trees is one of the most difficult things I have ever done. They’re planted six inches apart in rows a quarter of a mile long, so you’re counting along and if you get distracted by something you’re thinking, ‘Where was I?’ You’d think it would be a pretty simple deal to count them, but it’s not.”

The first count is done when the rootstocks are planted in March or April. The second is when the planting crew reports what they actually planted and in which row. The trees are counted again when they’re budded in August. In September, the trees are counted for the fourth time to see which buds survived. The fifth time is the following spring to find how they survived the winter. The last live tree count is done in September and the seventh when the trees are dug in November. In addition, the nursery might do another half-dozen partial counts to track specific variety or rootstock combinations. “All the time, we’re checking,” Tvergyak said.

The numbers change from count to count, particularly if a block is hit by a fireblight infection and replacement trees have to be planted. Once a fireblight outbreak has been stabilized, the trees are counted once more.

The reason for keeping an up-to-date inventory is to know how many trees the nursery has to sell and avoid overselling, he said. “You don’t really know what you have until you have them in hand.”

An automated tree counter would save a tremendous amount of work, he said. “If you could come up with some automatic thing, you could take less qualified people and have some confidence in the numbers.”

A tree counter that could also map the location of trees by variety and rootstock, perhaps using a Global Positioning System, would be particularly useful, Tvergyak added. •
Vacuum harvester PASSES BRUISING TESTS

Fruit looked “amazing” after its passage through the tubing system, says Extension educator.

by Richard Lehnert

The vacuum system apple harvester invented at Phil Brown Welding in Conklin, Michigan, was tested this fall in the orchards at the Pennsylvania State Fruit Research and Extension Center in Biglerville, Pennsylvania—and passed with flying colors.

“IT was amazing how beautiful the fruit looked after coming through the vacuum tubes,” said Dr. Tara Baugher, extension educator in Adams County.

Penn State horticulturist Jim Schupp said the machine did “very, very, very well.”

About 70 growers came to the center to see a demonstration on October 20—an excellent turnout considering apple harvest had not yet ended.

The primary focus of the tests at the research center this year was bruising, and some of the tests were conducted on some easily bruised apples—overmature Golden Delicious after three days of rain.

“We needed to focus on bruising,” Schupp said. “I needed to be able to tell growers with confidence, ‘this machine will not mess up your crop.’”

Some of the other data, while collected, did not do justice to the machine, he said. A combination of speed of harvest (labor use) and quality of fruit (packout) shows a gain of $245 an acre by using the machine.

“The trial wasn’t fair to the machine,” Schupp said. For a comparison, hand pickers harvested Golden Delicious growing on Bud.9, very small trees with minimal ladder setting needed, and the trial was small—so there were no worker fatigue issues. “We’re looking forward to doing commercial-size trials, with larger blocks,” Schupp said.

This vacuum harvester will be commercialized under the name DBR Conveyor Concepts. DBR stands for Dietrich-Brown-Rasch—Chuck Dietrich, Phil Brown, and Mike Rasch, the three men who developed it.

Part of the bruising test was done using the Impact Recording Device marketed by Techmark and once called an instrumented sphere. An apple-shaped ball filled with instruments records the knocks and bruises that occur as a fruit moves through a harvest or packing system.

Mike Rasch and Phil Brown traveled to Washington State in late October to meet with Washington State University’s Karen Lewis and Jim McFerson and arrange for further testing of their machine in Washington next fall.

Penn State and Washington State are partners, with others, in a U.S. Department of Agriculture-funded project called Comprehensive Automation for Specialty Crops.

Key components

The DBR machine contains several key components. One is the vacuum system that carries apples from a funnel-shaped receiver (into which pickers put the fruit) through neoprene-lined tubes to the bin. The next step is a decelerator, a foam wheel that stops the apples, removes them from the tube without losing the vacuum, and transfers them to the bin.

The next key element is the “elephant ear,” the fan-shaped apple distributor that takes apples and spreads them gently and evenly across the bin.

Pickers ride on a self-propelled, adjustable platform. A bin hauler holds five empty bins. A worker on the ground shifts a new bin into place as a bin is filled, and that filled bin is lowered to the ground. The bin hauler moves over it. The ground worker also oversees the bin filling, sorting out cull apples and doing other chores, Schupp said. •
**Tree Fruit**

**Harvest-Assist Technology: Getting Closer**

Harvest is finally winding down for tree fruit growers. Throughout the country, apple and pear prices are good, and could get better. The sweet cherry season could have been better, but was a welcome rebound from 2009. However, this is farming, so there must be a dark cloud somewhere.

Labor, unfortunately, might be the most ominous cloud on the horizon. Thanks to a down economy, we have enough orchard workers for now, but just barely. In 2010, H-2A programs, while working for some operations, are clearly not suited to provide the hundreds of thousands of workers needed in orchards throughout the country. And we cannot rely on Stephen Colbert, either.

But, wait! Could those clouds of labor woe be parting? Now, for the first time, it appears harvest-assist equipment is poised to go commercial.

At least three independent efforts are underway, and their prototypes are undergoing rigorous testing in California, Michigan, Pennsylvania, and Washington. They are also undergoing continual upgrading in machine shops when they aren’t running.

All three efforts have focused principally on apple harvest, although it is clear each could be utilized for other tree fruit with some modification.

All are designed to assist rather than replace the human front end of harvest. Each relies on a person physically identifying and picking individual fruit and includes platforms for picking the upper canopy. All will greatly improve the productivity, comfort, safety, and quality control of the harvest crew. All are aware of the need to minimize damage to fruit.

**Similar, But Distinctive**

The most complex project, a joint venture of Oxbo International Corp. and Picker Technologies, combines a highly-regarded ag equipment manufacturer with a start-up engineering firm. They have developed a dedicated track-based machine with novel, sophisticated transport, sorting, and pass-through bin handling capabilities. The transport system uses flexible pneumatic tubing, which singulates fruit from tree to bin.

While initially focused on apple picking, the machine has performed well with canning peaches and shows promise for many types of produce. Of particular note, the proprietary software and custom sorting component features on-the-go analysis of fruit number, size, and quality attributes, thus facilitating separation of packable and cull fruit in the orchard. The current machine performs best in high-density systems with planar fruiting walls.

A second project arose from collaboration between Auvil Fruit Company (AFC), a well-known, innovative tree fruit operation in Washington, and Van Doren Sales, a highly-regarded packaging line developer and manufacturer, also Washington-based. AFC has long used their custom designed and fabricated platforms for routine orchard operations, but has now added harvest to its capabilities. Workers still pick and place fruit into bags, but the bags are unloaded onto a sorting table where culls are hand-separated from packable fruit and dropped in the orchard. Bins are passed through the center of the machine. The platforms are optimized to function in AFC’s unique Tatura-type system.

The most recent project undertaken also results from a combination of an established ag equipment manufacturer and active tree fruit producers. Phil Brown Welding, Conklin MI, and two leading Michigan tree fruit producers, Mike Rasch and Chuck Dietrich, have formed a company called DBR Conveyor Concepts (DBR). Their prototype features pneumatic tubes transporting fruit after hand-picking into a dry decelerator and a dry bin filler. (For more information on this model, check out the June issue of American/Western Fruit Grower on www.growingproduce.com.)

While none of these approaches is commercial yet, both Oxbo and DBR are aiming for the 2011 crop season with products that are distinctively different and developed in close collaboration with tree fruit producers. Both are well aware of the need for robust, cost-effective equipment and working hard to expand application of their products beyond fruiting wall apple orchards. AFC remains committed to its harvest-assist path.

Certainly these three efforts are not the solution to the ongoing challenge of recruiting and retaining a productive and reliable work force in orchards across the country, but their progress and commitment make next year even more exciting. Despite a few clouds, really good news is on the horizon and getting close to U.S. orchards. •

Jim McFerson is manager of the Washington Tree Fruit Research Commission in Wenatchee, WA.

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Fruit Growers See Innovations in Action

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9/11/2010 2:00 PM

Chris Torres

Staff Writer

BIGLERVILLE, Pa. Fruit growers took a break from the peach harvest recently to meet with Gloria, Messina and Jersey Queen.

These are names of peaches, some of the dozens on display as part of a fruit research open house held at Penn State s Fruit Research and Extension Center (FREC).

Dozens of growers showed up to the open house, which featured tours of fruit plots, a presentation on robotics and overviews of what growers are already doing to make their jobs easier in the orchard.

Jerry Frecon, ag agent with Rutgers Cooperative Extension of Gloucester County, N.J., brought dozens of samples of peaches, nectarines and other varieties of fruit to show growers some of the research being done in the Garden State.

Even though he is considered one of the foremost experts on peaches on the East Coast, he said there are still things to be learned about different varieties of peaches.

I m always learning something new about peaches, Frecon said.

One variety, Gloria, he said is a challenging one to figure out because research has yet to figure out the optimal time to harvest the variety.

This season s peach harvest, he said, is 10 days ahead of schedule in the Garden State but is now leveling off. He said peaches may be smaller this year, but they are as flavorful as ever.

There are a lot of peaches and the flavor on peaches has been outstanding, Frecon said.

Growers also had the chance to see some robots in action.

Researchers from Carnegie Mellon University went into an orchard and showed off a Gatorlike vehicle equipped with sensors that was controlled by a handheld computer, similar to a small laptop or iPad.

The purpose of the demonstration was to show off the potential of robotics in orchards, mainly vehicles that can be remotely controlled or drive themselves and can do much of the work currently done by hand.

Carnegie Mellon, along with Penn State and dozens of other universities, are involved in a nationwide study to see the role robotics will have in the future.

Through a $6 million grant provided by the USDA s National Institute of Food and Agriculture, they are looking...
at ways robotics can be used for harvesting, spraying and thinning.

They are also looking at ways these robotic machines can help growers better estimate a crop yield, which could help them market their products.

It’s all a real nice mix of research, said Daniel Schmoldt, national program leader for instrumentation and sensors at the National Institute of Food and Agriculture.

The robotic component, of which Carnegie Mellon is leading, is two years in the developmental stage.

Matt Aasted, a PhD candidate in The Robotics Institute at Carnegie Mellon, said these robotic technologies could be available commercially within two years.

He said the computer interface, which was developed by a group of students at the institute, is designed to be mobile, so in theory it could be moved from a tractor to a platform and could perform whatever task it is assigned.

Speaking of technology, a tour of a nearby orchard in Aspers, Pa., showed off mechanical thinning technology already in use.

Paul Heinemann, professor of ag engineering at Penn State, said the thinners have already proved their worth in area orchards.

We’ve shown that the use of these thinners is efficient and economical, Heinemann said.

The next step is seeing how the technology evolves.

The goal is to create machines that can eventually operate on their own in an orchard.

Heinemann along with some assistants demonstrated a thinner placed on the back of a tractor. It had sensors attached to it that allowed for self-positioning in an orchard as well as a joystick that allowed for easier control by the driver. Thinners, right now, are usually placed on the front of a front-end loader and are controlled using the front-end loader controls.

Even with the current technology, growers have seen significant savings in labor and time.

Jim Schupp, professor of horticulture and acting director of FREC, said some growers using the thinners have reported 30 to 50 percent savings in labor.

We’ve seen significant savings as a result of using these thinners, Schupp said.

Henry Allenberg, owner of Allenberg Orchards in Smithsburg, Md., co-owns a thinner that he bought with another grower for around $15,000.

He grows 24 acres of peaches and says it has reduced his labor costs for thinning by around 40 percent.

The machine has already paid for itself in savings. We have some really good size peaches this years, Allenberg said. It’s easier to make half an investment in something you won’t use too much.

Schupp said he was most excited about the peach varieties, but robotics also have good potential.

He said the open house offered a little bit of everything for everyone.

There are a number of different things here where a grower can go back home and use it on their orchard, he said.

Gary Manoff, a grower from New Hope, Pa., said he was just pleased to see the support growers in Adams County get from their extension staff.

I think it was a good day. Just to see the support these guys get from their extension agents is good, Manoff said.

Even though he has been growing fruits for 25 years, he is still struggling to make his peaches ideal for a demanding market.

People want big peaches. They want them as big as your head. We’re struggling to get things right and do it
Andrew Schwalm of Schuylkill County, who grows 50 acres of apples and seven acres of peaches, said he was impressed with the many varieties of peaches on display. But he was excited to see robotics in action.

I was impressed with that autonomous vehicle and also surprised with the thinning system, Schwalm said.
Mechanical thin cherries

Mechanical thinning equipment has been tested for several years during bloom on apples and soft fruits, such as peaches and nectarines, but is now being tested prebloom for cherry thinning.

Two mechanical string thinners are being studied: the Darwin, which is commercially available in Washington State through Blueline Manufacturing of Moxee, and a prototype of the Bonner, which was developed at the University of Bonn in Germany. The Darwin, which has a single spinning spindle with cords, is most suited to a narrow canopy. The Bonner, which has three adjustable arms that can be placed into the canopy, can be used with any type of tree architecture including those that can’t be accessed with the Darwin.

Karen Lewis, Washington State University Extension educator for Grant and Adams counties, said that the Darwin thinner was tested in 2009 during bloom in the cherry orchard of Mark Hanrahan at Zillah, Washington, which is trained to the UFO (Upright Fruiting Offshoots) system.

“We did break up some of those big roped-on clusters last year, and we were pleased with the results,” Lewis reported during WSU’s annual cherry field day at Prosser in June. “It’s all about the cord hitting the target, so when we get a good placement into a block, like the UFO, we can do very well.”

This spring, she did further tests with the Darwin on a number of varieties in Hanrahan’s orchard at three timings: dormant (February), bud swell (March), and 50 to 60 percent bloom. Lewis said there were interesting results from the dormant treatment that will change how they approach field tests next year.

Rolf Lühs, an intern with the Washington Tree Fruit Research Commission who is assisting with the project, said the bud-swell timing—when the buds are 5 millimeter (about a quarter of an inch) in diameter—had the best effect. During the dormant season, it’s too difficult to hit the buds precisely, he said. When the thinning is done during bloom, it appears to knock off too many leaves, creating areas of blank wood, though more research needs to be done, he said.

Lewis said the dormant-season treatment removed about 5 to 10 percent of the full cluster buds and 20 to 35 percent of flower buds but did not damage the wood. “I was worried about blank wood then, but it turns out there was much less blank wood there than when we went in at bloom.

Lewis said results of chemical thinning on soft fruit do not translate directly into apples or cherries; apples have a lot of leaves at bloom and different flower morphology. “This is a key finding for us.”

The revolutions per minute and the ground speed can be adjusted on the mechanical thinners, depending on the tree arrangement and the desired effect. The rpm on the Darwin can be set between 200 and 400, and the ground speed is usually
The Darwin string thinner is attached to the front of the tractor. The Bonner is in the background.

“We did break up some of those big roped-on clusters last year, and we were pleased with the results.”

—Karen Lewis

between 2.5 and 3.0 miles per hour. Changing the cord arrangement also has an impact, Lewis said. More trials on cherries during the dormant and bud-swell stages will be conducted in the Southern Hemisphere this year with funding from a Specialty Crop Research Initiative grant and a grant from the Washington Tree Fruit Research Commission.

Hand-held thinner

Kevin Wang, a graduate student in WSU’s department of biological systems engineering, demonstrated a prototype hand-held thinner that was adapted from a commercial string trimmer. It has several different heads (known as end effectors) with a variety of sizes, lengths, and widths of cord. Lewis is working with WSU automation engineer Dr. Qin Zhang on the project, which is funded by the Washington Tree Fruit Research Commission and the Oregon Sweet Cherry Commission. WSU is applying for a patent for the concept, Lewis said.

Preliminary tests in UFO, steeple, and Spanish bush systems indicate that the spindle speed can impact the amount of bloom removed. At a high speed, 55 to 70 percent of the flowers were removed; at medium speed 19 to 54 percent; and at low speed, 6 to 41 percent.

However, Lewis said that the adapted string trimmer, with its gas engine, is too heavy and noisy for a person to work with for long periods of time. The end effectors will be developed with universal mounts so that they can be used with other power sources. She envisions that a tool could be developed with rechargeable batteries or an electric version could be used on a platform where it could be plugged in and set on a mount.

Dr. Matt Whiting, research horticulturist at the Irrigated Agriculture Research and Extension Center, said the challenge with bloom thinning of cherries—whether mechanically or chemically—is the unpredictable fruit set. Graduate student Allison Stewart is testing benzyladenine (BA), gibberellic acid (GA), naphthaleneacetic acid (NAA), ethephon (Ethrel), and six aromatherapy oils as potential postbloom thinners for cherries. ⋆

ELECTRIC farm vehicles

Washington State University Extension educators Karen Lewis and Gwen-Alyn Hoheisel are evaluating an electric all-terrain vehicle for farm use as part of the federal Comprehensive Automation for Specialty Crops project that they are working on. The four-wheel-drive Honda ATV was purchased from Barefoot Motors in Oregon.

Lewis said it cost twice as much as an ATV with a combustion engine. The lithium iron phosphate battery adds significantly to the cost, but the electric engine offers more opportunities, such as the ability to put sensors on the vehicle.

Lewis said battery science is moving ahead but no attention has been paid yet to evaluating battery size and battery life on the farm. “There are huge national studies looking at battery science for cars, but there’s nothing going on on the farm.”

Lewis and Hoheisel plan to study and document battery life in Washington State conditions, primarily focusing on use during cold winter weather.

The ATV will be used for studies with a tree caliper counter that is being developed as part of the automation project, as well as with the Weedseeker and other technologies. Another reason for choosing an electric ATV was that for sensor work, it needs to be driven at a slow, but steady speed, and it was fitted with cruise control. It has the capacity for cruising long distances at a very low speed.

At the field day, Hoheisel described how the Weedseeker, which was mounted on one side of the ATV, uses sensors to distinguish between green vegetation and brown ground. In recent trials, it saved a lot of spray material when compared with spraying the whole area.

The Weedseeker cost about $5,000, but the manufacturer, NTech Industries, Inc., claims that, depending on the weed density, it is possible to recoup the investment in one year through lower spray costs. Hoheisel said the technology is probably of most benefit to those who control their weeds fairly well, rather than those who have solid stands of weeds.

Autonomous vehicle

Lewis and Hoheisel have also purchased a prototype autonomous utility vehicle (known as an automated prime mover) for the automation project from Sensible Machines in Pennsylvania. Lewis said the vehicle has a removable scissor-lift platform on the back that can hold two people. This will give them the opportunity to evaluate smaller platforms than those generally used in the tree fruit industry, which hold four to eight people.

When used autonomously, the vehicle is guided by a laser system with an on-board computer. However, safety regulations would not allow that with people on the platform, so it can also be steered. She expects that it will only be used autonomously for research purposes. “There are a lot of things that have to happen before we use autonomous vehicles with humans in the field,” she said.

Blueline Manufacturing has a semi-autonomous system that can be used with people. Instead of using laser technology, it has a stick at the front of the vehicle that adjusts the steering when it contacts tree trunks as it moves down the row. —G. Warner
Welcome To The Machine

Apple growers are closer than ever to having an automated harvesting system suitable for their needs.

By Brian Sparks
Group Editor
June 2010

For years now, the apple industry has been in search of a practical and feasible mechanical harvesting system. Thanks to the efforts of a trio of innovators in Michigan, this vision may soon become a reality — and perhaps in a more convenient way than originally thought possible.

For the past year, fruit growers Mike Rasch and Chuck Dietrich, along with Phil Brown of Phil Brown Welding in Conklin, MI, have been tinkering with and modifying the design of an apple harvesting prototype they came up with. The latest version of this unit was unveiled during the International Fruit Tree Association's annual conference in the Grand Rapids area in early March, and it certainly caught the eye of those in attendance. "Everything looks very encouraging at this point," says Rasch. "We’re at the point where we have a good design that we can run with."

The prototype uses a vacuum system, with hoses that can pull the picked fruit into bins on a trailer. Up to four pickers can work at the same time, whether they’re on a platform or picking from the ground.

Flexibility Is Key

Rasch points to a long list of benefits this model provides to a grower, with perhaps the main advantages being adaptability to different equipment, and a modular power supply.

• Ease in accessorizing. This new prototype can be retrofitted to the equipment currently used by the grower. "The key was to make the power unit modular, so it can adapt to anything that can pull it, with or without a bin trailer," says Rasch. "We're not counting on just a tractor or platform as a carrying mechanism."

• More freedom for pickers. "The beauty of the vacuum system is that it does not lock you into a rigid work area," says Rasch. "You can carry the hose to wherever you are, whether you’re on a platform or on the ground."

• Minimal bruising. "We’ve been able to pick faster while still ending up with half the bruising that results from hand-picked fruit," says Brown, who made sure to trial the machine on varieties such as Goldens that are prone to bruising. As the apples move through the hoses, they go through an automatic decelerator until they roll off a fan-like device just inches above the highest filled point of the bin.

Award Winner

Phil Brown of Phil Brown Welding, who has played a key role in the development of a new apple harvesting prototype, was recently honored with an Industry Service Award during the International Fruit Tree Association's annual conference in Grand Rapids, MI, in early March. Accepting the award, Phil was quick to give credit to his wife Dorothy and sons David and Brian. As some of the growers in attendance noted, Phil is not only innovative in developing new equipment, "he can fix anything."
The next major focus, says Rasch, is on the durability and production efficiency of the unit, which (along with labor availability) will pave the way for meeting the needs of the grower.

Getting Closer
This past year, Rasch, Dietrich, and Brown formed an LLC called DBR Conveyor Concepts to develop, manufacture, and market the machine. This also includes the process of filing for a patent, which is currently pending. Each of these men brought their experiences in growing, engineering, and manufacturing to the partnership, which they hope will be beneficial.

So far Extension associates including Phil Schwallier at Michigan State University have already tested the device, including evaluating it side-by-side with a hand-picking crew, with positive quality results. As part of a USDA-funded project, they are now preparing to contract with Jim Schupp and Tara Baugher at Penn State University (PSU) for use in Pennsylvania peach and apple orchards this fall. It will be attached to a PSU platform for further evaluation. Assuming all goes well, the next step will be a similar partnership and evaluation with Washington State University’s Karen Lewis and Jim McFerson.

Rasch says there’s already a big interest among growers both nationally and abroad, which means the quicker to market the better. “We need to do some more quality control and durability testing, with more running time, before the end of this year,” says Rasch. Once that happens, each partner hopes it will be full steam ahead. “We’re happy with the input we’ve received at the university level, and I’m encouraged about the chance to get something out there,” Rasch says.
Steve Black, founder of Raemelton Farm in Adamstown, Md., is not afraid to ask "why." His determination to find improved production practices has led him down an interesting path filled with meters, monitors and autonomous vehicles.

Black’s approach to try new or underused ideas allows him to implement techniques while his nursery is still relatively small.

“We’re an infant in the industry, and it’s a whole lot easier to adopt new practices when you’re small, rather than when you’re huge,” Black said.

His goal is to find practices and tools that minimize labor expenses and environmental impacts, while maximizing plant growth.

“It makes sense to work on things like that now, so when we’re larger it’s all in place and ready to use,” Black said.

His progressive plans and willingness to try new things will only fuel the nursery’s growth, said Stanton Gill, extension specialist at the University of Maryland.

“He’s a progressive, thinking grower who doesn’t follow the crowd,” Gill said.

Gill has been involved in several experiments at Raemelton Farm. Black credits Gill with helping the nursery avoid common startup mistakes.

“Stanton was the first to conduct pest control trials at the farm and has been a huge resource for me,” Black said. “No other person outside our operation has been so important to our nursery.”

Irrigation innovation

The farm exclusively uses drip irrigation, which certainly cuts down on water usage. But when Black first began his nursery he wanted to know how much water to apply.

“No one could answer my question. I got a lot of ‘it depends’ or ‘1 inch per acre every week,’ which seemed to be the go-to answer,” he said. “But oaks don’t use the same amount of water as a maple. So I had to keep looking to find the optimum number.”

Black became a participant in a project funded by a USDA grant using real-time soil moisture monitors. The project is led by John Lea-Cox of the University of Maryland’s department of plant science and landscape architecture.

Two blocks of trees are equipped with a 12-node commercial wireless sensor network. The sensors monitor the soil water status at 6 inches, 12 inches and 18 inches within the root zone of six Acer rubrum Red Sunset and six Cornus florida ‘Cherokee Princess’ in real time.
"The sensors are hooked to a radio transmission box, which reports the percentage of available water in the soil every 15 minutes," Black said. "I can actually see between the two nighttime measurements how much water those trees use during the day."

Even with drip irrigation, water is sometimes pushed below the root zone.

"If I run the irrigation system so I never see changes in moisture at the 18-inch depth, I know I'm not wasting water," he said.

This is the second year of a five-year project, so it's too preliminary to know just how much water he's saved. But it has provided enough information to adopt a more efficient way to water.

"With these soil moisture monitors, I looked at a four-hour run once a day and a two-hour run in the morning followed by a two-hour run in the afternoon. By breaking it up twice a day, I found it gave us the greatest lateral movement of water," he said.

The primary objectives of this study are to evaluate the performance of these sensors and the capability of the network to provide real-time data so growers can make more effective day-to-day irrigation decisions.

Perfecting IPM
Raemelton Farm has a comprehensive integrated pest management program in place — something Black adopted from the beginning.

"The only thing we don't do is releases because we have such a healthy population of naturally-occurring beneficials," he said.

When potato leafhopper started attacking some of his stock, he partnered with the University of Maryland for another experiment.

"The conventional way to fight this pest is to spray a broad-spectrum pesticide three or four times a summer," he said. "Since this pest gets on a lot of plant material, you're killing everything with six legs — good and bad bugs."

Instead, Black tried Flagship in his drip system once in the spring. He treated only the rows that needed it and he got season-long control. "It's on the Flagship label, but I get the feeling not many growers use it that way," he said.

To fight off ambrosia beetles, Black found a study at the USDA Agricultural Research Service testing trap trees.

"Instead of blasting a broad-spectrum insecticide, the pests go to the trap trees which are injected with ethyl alcohol," he said. "We tried it this spring. None of the trap trees got hit with ambrosia beetles, but we don't have a lot of problems with that pest right now. This is an emerging solution for an emerging pest."

Solutions don't always come out of university research. "Look at your IPM program and always evolve it," he said.

Soil savvy
While the soils at Raemelton Farm are some of the best in the county, Black continues to look for ways to improve soil fertility.

"Our grass aisles have to be mowed, so we're looking at dwarf grasses and fescue cultivars that only have to be mowed once or twice a year," he said.

He's also experimenting with cover crops to attract beneficial insects and improve soil fertility. He's currently trying crimson clover, forage radish and dwarf buckwheat.

"The forage radish is showing a lot of promise," he said. "The root system is 3 feet long. It's a source of slow-release nitrogen, it improves aeration and it chokes out winter weeds."

"It helps with our pre-emergent applications. We don't have to put one down until May instead of the typical March application," he said.

For more: www.raemelton.com; www.smart-farms.net.

By: Kelli Rodda
Machines With Vision

New "seeing" harvesters can scout orchards to detect apples.

February 2010

Editor's Note: This past October, Tony Koselka, Jillian Cannons, and Ryan Carlon of Vision Robotics Corporation (VRC) returned to Washington for further field trials of the Newton Scout, a vision-based system for automatic crop load assessment. The following report highlights their results.

Developed in part through the USDA-funded project Comprehensive Automation for Specialty Crops (CASC), the Newton Scout will revolutionize orchard operations by providing growers with a map that accurately maps fruit placement, fruit size, and number throughout the growing season. Fruit maps will be used to determine crop load, which in turn will give growers the information to develop harvest and marketing strategies. And this is just the beginning. Developing reliable vision systems that are robust enough for use in orchards opens up all kinds of possibilities in the area of pest and disease detection, plant health assessment, and the use of robotics at harvest.

The Newton Scout integrates stereo cameras with a custom image processing algorithm. The algorithms use classifiers to identify the apples, where the simplest classifier uses color and shape. For red apples, color is the primary classifier. For detecting green fruit, the Scout detects using statistical classifiers generated by boosting algorithms. The most challenging aspects of detecting fruit are occlusions, shadows, shape and color coincidences, and ambient lighting conditions such as bright sunlight. Once an apple is identified, the stereo cameras enable the system to determine its location and size.

The Vision Robotics field trial was conducted at Allan Brothers Othello Orchard in Washington. Prior to VRC's arrival, Washington State University (WSU) Extension Educator Karen Lewis, and interns with the Washington Tree Fruit Research Commission, hand tagged, mapped, and sized fruit on several rows of fruit. This data allows for the groundtruthing or validation component of the test. Koselka took time out to speak about the development of a similar unit that counts oranges with the interns.

On one of the field trials for that unit, Koselka asked the grower to estimate his crop. The farm manager responded with 1,200 bushels. For this test, Vision Robotics scouted and counted 1,900 — a sizable difference and one that would have a large financial impact.

As Koselka stated, "not only will it [Scout] be able to accurately count a crop and locate each piece of fruit, it will ultimately feed into a robot harvester that will pick all the apples.” And if that was not enough, Koselka added, "Oh, and a pruner is not far off either!"

Even More Potential

The Newton Scout utility will be enhanced in the future with the addition of other possible technologies, including near infrared (NIR). As Newton evolves, it will have multiple uses throughout the fruit growing cycle — for example, assessment of sugar and acid content and internal damage. CASC is also making progress in other automation fronts that bridge with Vision Robotics' work.

Carnegie Mellon University (CMU) researchers, led by Sanjiv Singh, are developing an Autonomous Prime Mover (APM) capable of towing the Newton Scout safely through entire orchard blocks. In the future, they will also automate an agricultural harvesting platform so that workers no longer need to climb on ladders to pick fruit. The APM’s multifunctionality, autonomous drive, and wireless networking could move it into the center of precision management of specialty crops.

The CASC team, led by CMU, includes engineers, scientists, Extension educators, growers, equipment manufacturers, and industry representatives. This plurality of expertise has led to synergistic endeavors that push the envelope in both the engineering and the science components of the project. For example, Ben Grocholsky at CMU is developing a geospatial system to map and locate each tree in an orchard; in cooperation with the plant science group, he was able to augment this information with local temperature and NDVI data that has the future possibility of being incorporated to detect plant stress and disease.

In another example of the synergy of the CASC team, during a field trial of an automated caliper measurement device, growers told the CASC team that a simpler tree counter would also be very useful. Singh's group returned to CMU and produced a prototype tree counter ready to be tested in weeks; they will return to nurseries and test the counter this fall. The total time from conception to development will be less than four months, and if successful, this device could go into production within a year.
Technology in new equipment to ease the workload

by Sally Colby

Ten years ago, most growers wouldn’t have guessed tools such as string thinners, drum shakers and platforms would ease the workload in the orchard. However, concern about the cost and availability of labor has spurred research efforts to increase production efficiency in orchards.

According to Gwen Hoheisel, Washington State University extension educator, the USDA set aside significant funds in the last farm bill for the specialty crop industry in a project known as Comprehensive Automation for Specialty Crops, or CASC. The program is funded by USDA-SCRI (Specialty Crop Research Initiative) and private industry, with the goal of developing comprehensive automation strategies and technologies for the specialty crop industry. CASC is a comprehensive program and includes six disciplines: crop assessment; pest, plant and soil monitoring; autonomous vehicles, outreach, socioeconomic analyses and commercialization.

In particular, CASC will focus on apple and ornamental and tree fruit nursery production in Pennsylvania, Washington and Oregon; states that account for 60 percent of the U.S. fresh apple production. Growers in the Northwest and Mid-Atlantic regions are also major producers of peaches, pears, cherries, grapes and crops grown in greenhouse systems.

“There have been tremendous strides in technology in our lifetime,” said Dr. Jim Schupp, Associate Professor of Pomology at Penn State’s Fruit Research Lab in Biglerville, PA. “Some of these technologies have been introduced to the fruit industry and we don’t even think about them any more. Other parts of technology haven’t been fully exploited.” Dr. Schupp added that innovations such as image analysis on apple packing lines and computerized inventory are in use, but there’s a lot of proven technology that still hasn’t been taken to the field. “We’re using the same kind of tractors and sprayers our grandfather used, we’re standing on our own hind legs to march around the orchard to count insects and traps,” said Dr. Schupp. “That’s 1980s technology.”

Dr. Schupp says CASC examines long term goals while putting short term achievements into practice. “The immediate measurable success is that it brought back engineering — full-strength — in specialty crops.” said Dr. Schupp, noting harvest labor as a prime example. “Harvest labor is the most expensive part of production,” he said. “Every growers’ dream is harvest that involves just a few people. However, in the meantime, there are some things we
can do. We've demonstrated we can gain labor efficiency and a degree of increased safety because now we don't have ladder accidents."

SCRI targeted $28 billion for researching labor innovations for orchard crops and vineyards across the United States in a ten-year period. For example, a project at Washington State University received a $3.8 million grant for “A Total Systems Approach to Developing a Sustainable, Stem-free Sweet Cherry Production, Processing and Marketing System.” In this project, plant physiologist Matthew Whiting and his team will take a multi-faceted approach as they examine genetics, growing systems and marketing.

One important piece of automation CASC will be examining is the autonomous prime mover that can ‘see’ trees and steer without human guidance. “Instead of using GPS to determine tree location, it uses laser as the machine moves down the row,” said Gwen. “The idea is that you take the technology of the lasers, the computer program, the algorithms and attach that to anything — to a platform, a sprayer, an ATV — whatever fits in your operation.” The prime mover will be able to aid in tasks such as insect monitoring, pest scouting, disease detection and crop load evaluation; all tasks that would normally be done by humans.

Dr. Schupp referred to automated picking systems for tree fruits as the holy grail of automation. “I think we’re on the road that will lead us to that,” he said, “but no one thinks it’s going to be immediate. What we’re doing now is the background work, and along the way there will be spinoffs that will come into use more rapidly.” For instance, a labor assist platform that steers and regulates itself rather than having to be driven would be more advanced than what’s currently available. “While it’s in the row, it can be somewhat autonomous,” said Schupp. “What we’re thinking is that it may provide a useful platform for data collection and similar tasks.” In this case, the platform is the prime mover; the basis of future technology. “Whatever new technology there is will be on a prime mover that drives itself throughout the orchard.” Dr. Schupp suggests that evaluations such as canopy, plant stress, drought stress, nutrient deficiency and insect hot spots are all potential tasks for the prime mover and its equipment.

Gwen says that a critical aspect of CASC will be to ask, “if we do good outreach and extension and increase two-way communication, do we get a better product faster?.” “Early adopters (of new technology) are really important,” she said. “We know that someone will adopt a practice, then tell a neighbor, and so on. They trust what each other says. We just try to present the opportunities.”

Ultimately, the most important beneficiaries of CASC will be consumers. “We really want to be part of the movement toward increasing health and wellness in the United States,” said Gwen, “and we’re going to do it through consumption.”
Tree fruit and orchard growers never know season to season how much product they'll produce, but they can consistently rely on one thing. Labor costs, with all the personnel it takes to walk the rows inspecting and picking the fruit, are intensive and expensive.

But help might be on the way, and it comes courtesy of something you might see on "Star Trek." A consortium that includes the U.S. Department of Agriculture, university faculty and extension members across the country as well as those in private industry are collaborating in an effort to automate and modernize much of the orchard system in an attempt at reducing labor costs and helping those orchard growers struggling to continue making ends meet.

The consortium calls its initiative the Comprehensive Automation for Specialty Crops, and its members say nothing less than the future of the specialty crop industry is at stake.

"We must stay competitive in the global market," said Gwen Hoheisel, a Washington State University extension educator who works closely with the initiative. "Our labor is expensive. Production costs are high.

"Any improvements we can make helps keep our industry sustainable."

The initiative, CASC for short, might have complex technology, but it's simple in concept – utilize the most modern technologies so that machines can accomplish much of what in the past has taken countless human bodies to do.

One of the centerpieces of the CASC effort is what it calls an autonomous prime mover, a series of lasers and software that can be mounted to a four-wheel vehicle or to a semi-autonomous platform pulled behind a vehicle that effectively steers the vehicle automatically, reducing labor costs. The APM can "see" the trees in an orchard and steer itself down the open lanes between rows.

"The idea behind the autonomous prime mover is a laser technology that has the capability to auto-steer," Hoheisel said. "Auto-steering is available now in some farm equipment, but it is through the use of (global positioning systems), which is difficult to utilize in closed orchards."

The APM can perform a variety of tasks that normally would require laborers to perform, such as insect monitoring and elimination, weed management and detection and plant stress and disease detection.

"You can take this auto-steering laser technology and put it on any machine," Hoheisel said.

Hoheisel was quick to point out that the consortium's CASC initiative doesn't stop at the APM. Other projects are being worked on in areas such as socio-economic development, pest management tools, disease detection and crop load management. Hoheisel pointed to a project currently underway involving an automated tree caliper that measures the diameters of trees in an orchard without the need of labor.

CASC is operating on a $6 million USDA grant that is part of the Specialty Crop Research Initiative contained in this year's Farm Bill. Another $6 million will be put forth in land use, equipment and salary contribution by members of the consortium.
Ready for ROBOTS?

New technologies will improve orchard efficiency, but will your orchard be able to accommodate them?

GERALDINE WARNER

Scientists across the country are working on a $6 million, four-year project to develop automated equipment for apple production. A team at Carnegie Mellon University in Pennsylvania has developed a prototype of an autonomous vehicle designed to be used for a variety of orchard applications, such as insect monitoring, weed management, and plant stress and disease detection. There are also efforts under way to improve crop forecasting and harvesting efficiency with new technology.

But any kind of automated orchard equipment will work best in modern orchards where the trees are trained to a vertical axe system or fruiting wall, said Dr. Sanjiv Singh, robotics professor at Carnegie Mellon.

"The question is how soon is the grower going to adopt that," he said.

Prototype

The Carnegie Mellon team began working on the autonomous vehicle last October. The scientists purchased an electric utility vehicle and modified it so that it can be programmed to drive up and down specified orchard rows without needing a driver or operator. The vehicle, which can function day or night, can tow a mower, sprayer, or other piece of equipment while carrying a variety of...
Researchers find fertile field for innovation in labor-intensive agriculture

By Mike Cronin

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Researchers find fertile field for innovation in labor-intensive agriculture

American apple growers can't predict the yield of each year's crop, nor the size of fruits that make up annual harvests. "Orchard agriculture is the exact opposite of a modern factory," said Sanjiv Singh, a research professor at Carnegie Mellon University's Robotics Institute. "In manufacturing, managers can decide how many of something they produce and when."

But growing specialty crops — apples and oranges, for example — relies on people walking among rows of trees, examining fruit health, checking for bugs and noting branches that need to be thinned or pruned.

"What we're trying to do is increase the efficiency of producing apples," Singh said last week, standing at the edge of one of the Soergel Orchards in Franklin Park. A robot sitting about 10 yards away might help them do that, say Singh and a team of scientists.

The robot, a red Toro four-wheel-drive vehicle, is part of a four-year, $6 million project funded by the U.S. Department of Agriculture that began last year, said Daniel Schmoldt, a USDA official based in Washington.

Using lasers that sweep a 200-degree field of vision and computer programs that locate the middle of the tree rows, the robot maneuvers inside the orchard at about 3 mph, said Bradley Hamner, a CMU Robotics Institute researcher.

"It'll collect 100 times more data than a human would," said Morikawa, CEO of Vision Robotics Corp. in San Diego. "Growers are in the commodity business. If they're able to forecast how many apples of a certain size they're producing, that gives them tremendous market opportunities."
Mechanization has made the modern farmer's life a lot easier. That's especially true for those who grow crops like wheat, soy or corn on big, broad fields. But the story is quite different for growers who raise fruit, nuts, vegetables or nursery plants.

These so-called specialty crops - a $45-billion-a-year business in the United States - require intensive hand labor. Faced with rising labor costs, a shortage of workers and increasing demand for safe and affordable products, specialty growers are desperate for ways to boost food quality without boosting its price.

One answer, says Craig Senovich, may be robotic technology. Senovich, an engineer by day, opened Half Crown Hill Orchard four years ago in an overgrown field on land that his great-grandfather used to farm vegetables.

"There were a lot of crab apple trees and brush, and it took us several months just of digging out trees and clearing the land and preparing the soil," he says.

Senovich fenced in a 1.2-hectare plot, planted 1,300 trees and installed a drip irrigation system. Field sensors and a weather station are linked to his personal computer and track data related to the crop's well-being.

Half of Crown Hill Orchard is also a robotic technology test site for a United States Department of Agriculture project looking at ways of mechanizing the production of specialty crops like apples.

"It would be nice to be able to have some automated stuff just to mow the lawn," he says, reflecting on a chore that takes him several hours.

Sanjiv Singh, a Carnegie Mellon University robotics professor and principal investigator on the USDA project, says that task would be easy. He's at the orchard testing a battery-powered electric utility vehicle that drives itself. A laptop computer is the only passenger. Two laser scanners mounted on the front bumper, each taking 13,000 measurements per second, help plot its course.

"It sends the command to a controller on the vehicle, and that
adjusts the steering and speed," says Singh.

On this day, the robotics team explores how the unmanned vehicle gets around.

"This technology coupled with sensors already available might give farmers a lot more information," says Singh, who envisions its application would allow growers to monitor more frequently.

Another USDA applied robotics project takes Cris Dima to Florida. The southeastern U.S. state is second only to Brazil in citrus production worldwide. Dima is a scientist at the National Robotics Engineering Center at Carnegie Mellon, and he has just spent several weeks in one of the state's largest orange groves testing a network of autonomous, or driverless, tractors. He says the farm could be monitored virtually from an office or from somewhere in the field.

"Four or more autonomous tractors could run simultaneously and perform operations such as spraying or mowing."

Robots could also be engineered to administer precise amounts of water or chemicals to specific trees. Dima says the goal is not to develop an entirely autonomous operation, but rather to integrate technology the farmer needs at an affordable price.

"Beyond proving that this is possible, there is work to be done in reducing the cost of the technology, making it robust and transferring it to somebody who can commercialize it."

Back at Half Crown Hill Orchard, Sanjiv Singh says it's going to take growers like Craig Senovich, engaged in the process, to move this technology into the marketplace.

"We've been working on this robotics [automation] technology for 25 years, and from a technology perspective, some of the things are well in hand."

The challenge, he adds, is to develop technology that can help generate enough money for growers.

Senovich nods in agreement as he watches the electric vehicle drive itself safely down rows of budding trees in his orchard. He's hoping these test runs will soon advance to the next step and start providing fruit and vegetable growers with some automated and money-saving solutions.
While waiting in the Philadelphia International Airport for the last plane in a long trip home from Italy in 2006, Katy Lesser worked on a PowerPoint presentation that, unbeknownst to her, would eventually lead to a $1 million grant from the federal government. Lesser, coordinator of Penn State Cooperative Extension’s Ag Innovations initiative in Adams County, was returning from InterPoma, an international agricultural trade show featuring the latest European technology for apple production, storage, and marketing. She’d been particularly interested in orchard platforms—mobile machines that move picking crews through orchards faster than the traditional box-and-ladder method. But what ended up grabbing her attention was something completely different: the German-made “Darwin string thinner,” a device that removes tiny apples early in the growing season so remaining apples can grow larger and become more valuable.

At the Fruit Research and Extension Center in Biglerville, Ag Innovations coordinator Katy Lesser is shown with a Darwin string thinner, a machine she first saw at a European trade show.
“I liked the string thinner immediately,” Lesser says. “I knew some of my colleagues had been working on chemical ways to thin peach blossoms. With peaches, crews remove blossoms instead of immature fruit. It’s labor intensive, so growers have been experimenting with chemical thinners. But consumers balk at the use of chemicals. The Darwin string thinner seemed like a simple solution. I don’t have a horticulture background, but I thought it made sense to consider using this device with peaches.”

Lesser presented the Darwin thinner to the Ag Innovations advisory committee the next day, then again at extension’s Winter Fruit School. “We had producers out of their seats the moment Katy’s talk was over saying, ‘We have to have that string thinner,’” says Jim Schupp, a pomologist at Penn State’s Fruit Research and Extension Center in Biglerville. “There is an acute awareness in the fruit industry that we can’t continue doing things the way we always have.”

To provide the size and quality of fruit consumers expect, growers must carefully manage crop loads in stone fruits such as peaches. That means thinning blossoms by hand—an expensive and labor-intensive process. Alternatively, growers have tried chemical thinners. These sprays will eliminate a certain percentage of the blossoms but provide no control over which blossoms are killed. And it takes time to gauge the effectiveness of the application.

“It’s unlikely anyone will invest in developing a new chemical thinner; the economics don’t support it,” Schupp says. “And with mechanized thinning, you see the results immediately.”

Making the decision to try the string thinner was easy, according to Lesser. “Getting it here was another thing,” she says. “The Fruit Research and Extension Center partnered with industry to cover the cost, but try ordering a large, unusual piece of machinery over the phone from Germany when you don’t speak the language.”

Luckily, Lesser knew a local family hosting a German exchange student. The high school student translated and helped work out details with the vendor to get the machine to Biglerville.

When the machine finally arrived, Schupp and extension educator Tara Baughner began experimenting. While the Darwin string thinner works non-selectively—removing blossoms from fruit trees in a more-or-less random fashion—Schupp and Baughner wondered whether a selective machine could be developed that considers which blossoms would be best to remove. To do that, they needed an engineer.

The inclusion of dedicated specialty-crop research support in the 2008 Farm Bill may signal a shift from a strictly cheap-food mindset of policy making that previous Farm Bills embraced to one that more closely reflects consumer taste and interests.

Opportunity Knocks
In the meantime, growers of fruits, vegetables, and other horticultural crops were pressuring Congress to add a specialty-crops title to the 2008 Farm Bill. They received support from many non-corn-belt legislators, such as Pennsylvania U.S. Senator Robert Casey Jr., who told an audience at Penn State’s 2007 Ag Progress Days event that he would work to achieve regional equity so that the bill would account for the diversity of the state’s agricultural industry. “Our fruit and vegetable growers receive only marginal assistance,” he said, “even though we have specialty crops all across Pennsylvania that account for 51 percent of all farm receipts. And you know the list—we’re in the top ten in virtually any specialty crop you talk about.”

Indeed, Pennsylvania has a wide diversity of specialty-crop operations. Besides being the nation’s top producer of mushrooms, the state is among the leaders in the production of pumpkins (third), apples (fourth), grapes (fourth), peaches (sixth), and snap beans (sixth). Nationally, specialty crops constitute an industry worth $49 billion annually.

The lobbying effort was successful. While commodities such as corn, soybeans, peanuts, sugar, and wheat are traditionally the major beneficiaries of Farm Bill support, so-called minor crops (now referred to as “specialty crops”)—which include fruits, vegetables, tree nuts, and nursery crops—received new, dedicated funding in the Farm Bill of 2008. Under the legislation, growers will not receive direct crop subsidies. However, the Spe-
cialty Crop Research Initiative will provide funding for studies to develop sustainable and profitable solutions to the unique problems they encounter.

Specialty crops make up a lot of what you see for sale in the grocery store. All the fresh fruits and vegetables in the produce section are specialty crops. Wander up and down the canned-food aisles and most of these products, as well as those in the frozen food cases, are specialty crops. These are the foods that make our plates rich. Research will help ensure that the supermarket—and the farmer’s market—remains stocked with fresh, safe foods with longer shelf lives and greater availability throughout the year. In addition, new technologies will reduce the impact of labor shortages and rising labor costs, helping growers maintain profits in the face of rising energy costs. And all of this is happening as consumers demand better quality, different options, and good value at the grocery store.

In the first fiscal year of the new Farm Bill, the U.S. Department of Agriculture authorized $28 million in grants for specialty-crop research. The narrow application window and competitive environment favored those with strong connections to industry and collaborations with other institutions. Largely because the College of Agricultural Sciences had both, it was the lead institution or a participant on three proposals funded for $7 million—25 percent of the total allocation.

“The college was well positioned to respond in this area,” says Bruce McPherson, the college’s associate dean for research, who notes that Penn State has a long history of research and extension programs related to specialty-crop production. “We either led or were part of sixteen proposals to this initiative, and faculty had one month to respond from the time that the requests for applications were issued from USDA. I would argue that represents a bit of pent-up demand. On top of that, these grants required a 100 percent match from funding sources that were not federal.”

That’s where the college’s industry connections came in. Support for the mechanical-thinning project didn’t just happen overnight but developed over years of collaboration, so when the time came to raise a million dollars in matching funds, the right connections were already in place.

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Building a Better Thinner

Two years elapsed between Katy Lesser’s Italy trip and the call for research proposals that followed passage of the 2008 Farm Bill. During that time, it became apparent to Schupp and Baugher that mechanical thinning was a viable option for Pennsylvania’s fruit industry. This led the group, including agricultural engineer Paul Heinemann, to apply for and receive one of the first specialty-crop research grants funded by the bill.

Heinemann is the principal investigator of the project, which will look at in-
novative technologies for thinning fruit with the aim of advancing the development and use of mechanical thinners in peaches and other tree fruits.

“We proposed to further test and refine nonselective thinners,” says Heinemann. “But we also hope to develop a selective thinner that knows which are the best blossoms to pick. Such a machine would require the use of advanced technologies such as machine vision and robotic mechanization to pull or cut off the blossoms, perhaps with high-pressure water or air jets. Working on selective thinners is a look toward the future.”

In addition to developing thinners, Heinemann notes that the researchers will also look at orchard structure. “It’s important to develop tree structure that is most suited to the machines,” he says. The scientists also will examine the socio-economic implications of this new technology so that growers can make informed decisions about when and how to implement it.

“Citrus, grape, and other tree and vine crops have the same mechanization needs that we find in apples or peaches.”

Reducing Labor Automatically
The new funding for specialty-crop research has supported the development of connections with nontraditional partners who have the special expertise needed to tackle a specific problem. Baugher, the tree fruit extension educator in Adams County, is the principal investigator for a project aimed at developing comprehensive automation systems for specialty crops. The nearly $800,000 project is part of a $6-million grant to Carnegie Mellon University.

“Citrus, grape, and other tree and vine crops have the same mechanization needs that we find in apples or peaches,” says Baugher. “We’ve started working together across production areas and with growers around the country to find funding and start solving some of the issues they’re facing. As we began to look at the challenges faced in automation, we realized we didn’t have people at Penn State working in robotics necessary for tree fruit demands. So we looked to Carnegie Mellon for their expertise.”

The project will focus on methods to significantly reduce production costs for fruit and other specialty-crop industries. Researchers will look at information, mobility, and manipulation technologies to improve decision making, enhance crop load scouting, and augment harvesting. Plant-science work—led by entomologist Larry Hull and plant pathologist Henry Ngugi at the Fruit Research and Extension Center—will be aimed at developing better ways to monitor insect infestations and detect plant stress and disease.

Each of these technologies and techniques will be assessed with respect to social and economic feasibility and tested both in the lab and in the field to make sure they are effective and affordable.

Understanding the Market
A third Farm Bill–funded project, led by horticulturist Kathy Kelley, will bring...
A project led by horticulturist Kathy Kelley will help the Mid-Atlantic specialty-crop industry respond to new marketing opportunities and evolving consumer demands.

Together a Mid-Atlantic coalition of specialty-crop producers, processors, wholesalers, retailers, researchers, and educators in a series of discussions culminating in a strategic-planning conference to address issues related to consumer demand, marketing, production practices, and research and extension-education needs.

Consumer demands for variety, availability, safety, and quality are placing increasing pressure on specialty-crop producers. In addition, rising transportation costs for producers in California, Florida, and southern-hemisphere countries that supply fresh fruits and vegetables to the Mid-Atlantic region are creating opportunities for local specialty-crop producers. But to meet these demands and capitalize on these opportunities, growers need knowledge.

Kelley says the $100,000 project will help industry and academia make sound decisions about how best to focus resources. “Conference participants will identify issues to be addressed through research and help guide development of educational programs to make businesses more profitable,” she explains. “We’ll develop action plans that include best-practice approaches to production, integrated pest management, processing, and food safety.

“Producers want help understanding consumer behavior so they can use that information to expand and improve their businesses. But first we need to know what is taking place—and what is changing—in the market.”

that more closely reflects consumer taste and interests, says one Penn State agricultural economist.

“People are interested in eating healthier, interested in locally grown food or maybe organic,” says Jeffrey Hyde, who often works with producers interested in specialty crops and alternative agricultural enterprises. “These characteristics are more often associated with specialty crops than they are with commodity crops. It signals an acknowledgment that consumers have changed their minds to some degree about the foods they eat and the characteristics of that food. Supporting specialty crops will help meet those evolving demands.”

Faculty and staff referenced in this article are Katheryn Lesser, extension educator and coordinator of the Ag Innovations initiative in Adams County; James Schupp, associate professor of pomology; Tara Baugher, tree fruit extension educator in Adams County; Bruce McPherson, associate dean for research and graduate education; Paul Heinemann, professor of agricultural and biological engineering; Larry Hull, professor of entomology; Henry Ngugi, assistant professor of plant pathology; Kathleen Kelley, associate professor of horticultural marketing and business management; and Jeffrey Hyde, associate professor of agricultural economics and extension state program leader for entrepreneurial and value-added agricultural systems.

Other institutions collaborating on the projects described include Carnegie Mellon University, the University of California—Davis, the University of Maryland, Washington State University, Clemson University, and the University of Illinois.

Funding is provided by the State Horticultural Association of Pennsylvania, the Pennsylvania Department of Agriculture, the U.S. Department of Agriculture—Agricultural Research Service’s Appalachian Fruit Research Station, the Washington State Tree Fruit Research Commission, the California Canning Peach Association, the South Carolina Peach Council, and commercial grower-cooperators in Pennsylvania, Washington, California, and South Carolina.
The weed seeker has sensors that detect and spray only weeds on the ground—resulting in the use of fewer pesticides.

Carnegie Mellon University Robotics Institute, Penn State and other institutions are developing an autonomous vehicle that will drive itself around an orchard, allowing the driver to tend to other things.

Preview of future — robots come to Biglerville

A team of engineers from the Carnegie Mellon University Robotics Institute (CMURI) recently loaded up their robots and started driving east. They were headed for the Pennsylvania Fruit Growers conference at Hershey Lodge.

"It's our challenge as horticulturists to put engineers in the best possible environment to design and test their new technologies," said Dr. Jim Schupp of the Penn State Fruit Laboratory. "We want to make sure that our technologies are as accurate as possible."

"We're trying to develop technologies that will allow for greater accuracy," said Dr. Schupp. "These technologies can be used in the future to help growers and fruit farmers."

While some of the technologies may be available to medium term. He then added, "It's good to see your life's work have an impact on people's lives. That's exciting!"

their cooperators are hopeful that their hard work developing new technology will result in growers having more capabilities. With new technology being developed and
The engineers came to Biglerville to work with Penn State, Purdue University, and USDA scientists on a multi-institutional research project focusing on Comprehensive Engineering Solutions for fruit and other specialty crops. The project was put together to address the need to improve economic, environmental, and social sustainability in orchard systems.

Robotics is just one part of the comprehensive automation project. The project is transdisciplinary and includes plant science, information manipulation, rural sociology, outreach and commercialization. Growers, technologists, community leaders and equipment manufacturers are among those who will most benefit from the research being done. As project scientist Ben Grocholsky explained, “This is an industry that needs help and the technology is here. This project is not about improving technology, but rather helping agriculture.”

Additional devices are being developed that can be attached to the autonomous vehicle, such as sensors that will be able to estimate the crop load and read the temperature of a tree to detect if it is stressed by a disease or lack of water. The engineers are also working on localization technology so that the vehicle can locate itself in the orchard without the use of GPS. Labo platforms and mechanical trimmers are other innovations that could be adapted to the new technologies.

While the engineers were in Biglerville, they conducted field trials on targeted weed control application technologies and row following with an autonomous vehicle. The Weed Seeker, which was developed by a commercial collaborator, NTech Industries Inc., is a sprayer with sensors to detect chlorophyll and it sprays only when it senses a weed. The autonomous vehicle is designed to accommodate attachments to do multiple tasks such as monitoring plant stress, counting insects in traps or mowing.

Having previously tested the equipment in Pittsburgh, the Carnegie Mellon engineers came to the fruit lab in Biglerville because they needed orchards of different styles, with different problems to assess.

Research and Extension Center

Next the engineers will take their equipment to Washington State orchards. The main purpose of the visit, said one engineer is to discuss the needs of growers and how the machinery can be modified to meet those needs.

“We’ve had really excellent grower input so far,” said Schupp, “we’re on our way, but it’s just the beginning.”

Jackie Libby, a member of the robotics team and a first-year student in the doctorate program at the Robotics Institute, said “I’m interested in agricultural applications because it has to do with issues worldwide, like sustainability and monitoring of the environment.”

Libby says that she is inspired by the prospect of detailed environmental trials and addressing some of its challenges in agricultural systems. Libby and Grocholsky explained that in agriculture, specialty crops is where there is both a need and a readiness to develop new technology.

During a demonstration of the equipment to local growers, project director Sanjiv Singh emphasized that much of the component technology being used for the project was already commercially available. The reason, he explained, is to keep the cost down, so that it could be mass-produced and made affordable for growers. A sentiment expressed by all engineers was that they wanted this technology to be useful and one day readily accessible to the fruit growing industry.

“I think it’s an opportunity for our technology to actually help people in the near future. And that’s a great thing,” said Singh. “Much of the technology doesn’t always see the light of day in terms of application.”

But this project, he said, has “viable applications in the near
Carnegie Mellon developing automated systems to enable precision farming of apples and oranges

In Brief: Two groups of researchers at Carnegie Mellon University’s Robotics Institute have recently received a total of $10 million in grants from the USDA to build automated farming systems. One is for apple growers, and one is for orange growers, but both are designed to improve fruit quality and lower production costs.

Automated farming systems use sensors on autonomous robotic vehicles or at fixed sites within orchards to gather a multitude of data about tree health and crop status. Robotic vehicles will be used to administer precise amounts of water or agricultural chemicals to specific areas or trees. The vehicles also will be used to automate routine tasks such as mowing between tree rows.

The projects were funded through the USDA’s new Specialty Crop Research Initiative. The Comprehensive Automation for Specialty Crops (CASC) Program, led by Sanjiv Singh, research professor of robotics, received a four-year, $6 million grant to develop systems for the apple industry. The Integrated Automation for Sustainable Specialty Crop Farming Project, led by Tony Stentz and Herman Herman of the Robotics Institute’s National Robotics Engineering Center (NREC), received a three-year, $4 million grant to develop systems for the citrus industry. Both project grants will be matched dollar for dollar by industry, state governments, and other funding sources.

“We are taking automation to a level never before demonstrated in an agricultural setting,” said Herman of the NREC project. “This will provide an early look at how the automated farm may someday operate and promises to deliver insights and lessons far beyond what should be expected from small demonstrations of autonomous scouts.”

“Mobile sensors and computer tracking will enable growers to monitor their orchards in unprecedented detail,”

An apple “fruited wall” in bloom. (Photo courtesy of the Washington Tree Fruit Research Commission)

A conventional apple harvest, with no robotics in sight. (Photo courtesy of the Washington Tree Fruit Research Commission)
said Singh. “Growers will receive early warning of diseases and insect infestations, as well as continuous updates on crop status. With this information, growers can make timely decisions that will save them money and improve the quality of their crop.”

Although Carnegie Mellon is not a university traditionally associated with agricultural research, the Robotics Institute’s Field Robotics Center has been involved in agricultural automation since the early ’90s and the NREC has worked with agricultural equipment manufacturers since it opened in 1996. Moreover, both organizations are experienced in managing research programs involving academic, industrial, and governmental researchers working closely with end users.

“This level of collaboration between academia, government, and industry is not at all common in agricultural research,” said Jim McFerson, manager of the Washington Tree Fruit Research Commission. The technologies developed will be applicable not only to apple and orange growers but to producers of all kinds of tree fruits, he added.

“Growers can use the data generated by this new approach to make decisions throughout the year regarding pest management, pruning, fertilization, irrigation, and yield estimates,” McFerson said. “We believe this will result in higher quality fruit at a lower per-unit cost, as well as a more productive and safer workplace.”

The CASC Program will work with apple growers in Pennsylvania, Oregon, and Washington and includes collaborators from Penn State, Washington State, Oregon State, and Purdue universities as well as the USDA Agricultural Research Service. Researchers will use a fleet of automated four-wheel vehicles that can perform multiple tasks, including tree monitoring and chemical spraying. Industrial partners include Toro, Trimble, Vision Robotics, IONco, and Sensible Machines.

The NREC’s Integrated Automation for Sustainable Specialty Crop Farming Project will deploy a fleet of networked, unmanned tractors in the orange groves of Southern Gardens Citrus (SGC), one of Florida’s largest growers. In addition to SGC, collaborators include researchers at the University of Florida, Cornell University, and Deere & Co.

Harvesting remains one of the most labor-intensive operations in orchards, but it also is very challenging to automate because of demanding handling and cost requirements. Both projects will investigate new designs for mechanical harvesters, including a vacuum-assisted device that the CASC will use for apple harvesting, but the emphasis will be on aiding human harvesters, rather than replacing them.

The Specialty Crop Research Initiative was established by the 2008 Farm Bill to solve critical issues facing specialty crops, which include fruits and vegetables. The two Carnegie Mellon-led projects were among 18 that received a total of $28 million in the first round of grants last fall. The Robotics Institute is part of Carnegie Mellon’s School of Computer Science.

For more information contact Byron Spice, bspice@cs.cmu.edu or go to www.cmu.edu.
Tree Fruit: Precision Ag Coming Into Focus

Precision agriculture is a powerful concept, especially as fruit and nut producers look harder than ever for any competitive edge.

By Jim McFerson

February 2009

The recent annual meeting of the Washington State Horticultural Association (WSHA) had sustainability as its theme and highlighted the transition we are undergoing as a new generation assumes leadership. That generation includes some amazing young people, more women, and more Hispanics. Our producers are growing in diversity along with the products we offer.

Attitudes at the meeting were upbeat and positive, even as the Washington apple crop grew by millions of boxes. Somehow, the precision of our crop estimation, never very good, seemed to lack any precision whatsoever.

Precision agriculture is a powerful concept, one particularly suited to the readership of American/Western Fruit Grower. Fruit and nut producers are looking harder than ever for any competitive edge. This doesn’t mean simply cutting costs; rather it requires a focus on consistently providing a product the consumer prefers and doing so by optimizing per unit costs of production.

Thus, it would seem that implementing more accurate and exact management agricultural practices (precision agriculture) makes perfect sense for all specialty crops. After all, these industries are accustomed to capital- and management-intensive farming: High-density plantings; complex systems to deliver water, nutrient, and plant bioregulator inputs; specialized equipment; complicated and expensive harvest handling and processing procedures; well-trained managers, consultants, and work force — all business as usual.

Investing In The Future

Most producers have long been using the accurate and exact approach of integrated pest management. Most are now computer literate and ready to utilize Internet-based communication via smartphone, laptop, or desktop. Mechanization of pruning, spraying, and harvest is common in many fruit and nut operations, although it is often inaccurate and inexact, and messy to boot.

Escalating labor and input costs, along with regulatory demands, render precision agriculture the obvious course. Why, then, has it remained only a concept for specialty crops?

I have no easy answer. I have written in previous columns about efforts to develop engineering solutions for specialty crop challenges. These partnered efforts involve commodity associations, private sector technology providers, and leadership from USDA administrators like Tom Bewick, Dan Schmidt, Sally Schneider, and Jeff Steiner. Unfortunately, what I have written has been like specialty crop implementation of precision agriculture — mostly conceptual.

Meetings, reports, trips to DC, more

Getting Automated

While all the projects funded by the Specialty Crop Research Initiative are fascinating, one is already having impact. Titled “Comprehensive Automation of Specialty Crops (CASC),” this is the largest single project, with a series of research objectives: environmental sensing; detection of crop load, plant stresses, pests, and diseases; reconfigurable mobility platforms; and database development and decision-aid systems. It’s an ambitious project designed to allow producers to make more exact and more accurate decisions, and provide them with technologies to implement those decisions. Work focuses initially on apple and nursery crops, but is expected to extend across specialty crops. Check out the project website for more details:

http://fieldrobotics.org/casc/Welcome.html

Beyond its scope, the CASC project is remarkable for the composition of its research team. Of the 12 project partners, half are private sector technology providers, four are land grant universities (Oregon State, Penn State, Purdue, and Washington State), and one is an ARS lab ( Kearneysville,
meetings, etc. Dormancy-inducing. However, in the past couple months, things are starting to liven up. Teams associated with projects funded by the Specialty Crop Research Initiative (SCRI) have been organizing. The great goals of the SCRI are being addressed: develop a competitive process to fund research and Extension teams; engage stakeholders; use an integrated approach to addressing critical issues; and emphasize outreach and economic impact. Additionally, the magnitude of funds allocated matches the importance of the proposed activities, with around $28 million in USDA funds. Since each project was also required to demonstrate 100% matching funds, much of that from commodity organizations and private sector technology providers, the total investment is really around $55 million.

For more information on all of the 27 funded projects and to access abstracts for each, go to http://www.csrees.usda.gov/newsroom/news/2008news/10081_scri.html.

The SCRI represents the kind of innovation specialty crop industries require. Why, if we are successful, crop estimates for 2009 might be a little more precise ...

Finally, I cannot write this column without acknowledging the passing of Tom Mathison, an industry leader who personified innovation throughout his life. Mathison was a critical figure in raising the profile of research in the Washington tree fruit industry and beyond. He leaves behind a tremendous legacy.

About the author:
Jim McFerson is manager of the Washington Tree Fruit Research Commission in Wenatchee, WA.

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Picking apples with a robot

By Roland Piquepaille | December 8, 2008, 10:10am PST

According to Carnegie Mellon University (CMU), specialty crops (fruits, vegetables, horticulture and floriculture) constitute a $45 billion/year industry in the U.S. alone, of which the tree fruit and nursery industries have a farm gate value of $20 billion/year. But because the fruit are hand-picked for the most part, labor costs are exploding and represent 58% of the net value of the farm economy. So two teams of researchers at CMU are developing automated farming robotic systems to help apple and orange growers. The groups are using $10 million in grants ($6 million for apples and $4 million for oranges) from the U.S. Department of Agriculture (USDA)’s new Specialty Crop Research Initiative. But read more...

You can see above a prototype of a robot vehicle for apple growers which is currently tested at Soergel Orchards, located in Wexford, PA. Here is a link to a much larger version of this photo.

Now, let’s go back to the two USDA-funded projects. The Comprehensive Automation for Specialty Crops (CASC) Program, led by Sanjiv Singh, research professor at the CMU’s Robotics Institute, received a four-year, $6 million grant to develop systems for the apple industry. [Please note that I’ve already wrote about Singh last month in Robot helicopters flying low among obstacles.]

And the Integrated Automation for Sustainable Specialty Crop Farming Project, led by Tony Stentz and Herman Herman of the Robotics Institute’s National Robotics Engineering Consortium (NREC), received a three-year, $4 million grant to develop systems for the citrus industry. Both project grants will be matched dollar for dollar by industry, state governments and other funding sources.

Now, let’s look at the CASC site. The Singh’s team is actively working at Soergel Orchards. Here is a link to the visit the team made on November 14, 2008. “We did our first autonomous run at Soergel Orchards using an electric utility vehicle that has onboard computing and sensing. The path followed was 1.3 km long using GPS waypoints at speeds between 2 and 3 m/s. The path
was four 150 m legs in rows spaced about 26 feet between centers.” You can see a short video from the above link and see more pictures from this image gallery.

The team returned to Soergel Orchards on November 24, 2008 to acquire range data using laser scanners. Of course, the researchers took a bunch of other pictures.

For more information, you also can read Orchard robotics makes one juicy project (David Templeton, Pittsburgh Post-Gazette, December 3, 2008). Here are the last paragraphs of this article. “Mr. Soergel said ‘the most exciting part is keeping prices as low as possible and cutting costs’ at the orchard his family has operated since 1850. One priority is giving an early alert to growers when insects arrive or disease shows up. For now, Dr. Singh’s team is developing a way for their robotic vehicle to understand where it’s situated in the orchard. Larger orchards already use moving platforms that proceed slowly, tree to tree, and can be raised or lowered depending on the fruit’s location. An immediate goal is a platform that travels without a driver. ‘We’re taking baby steps,’ Dr. Singh said. Or, as he notes with a wry smile, ‘we’re picking the low-hanging fruit.’”

_Sources: Carnegie Mellon University Robotics Institute news release, November 19, 2008; and various websites_

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Biography

Roland Piquepaille passed away in early January 2009. He lived in Paris, France, and spent most of his career in software, mainly for high performance computing and visualization companies, working for example for Cray Research and Silicon Graphics. He left the corporate world in 2001 after 33 years immersed into it. In 2002, he started a blog about technology
Orchard robotics makes one juicy project

Wednesday, December 03, 2008
By David Templeton, Pittsburgh Post-Gazette

Brad Hamne, of Baton Rouge, La., checks the sensors on the front of an electric golf cart with robotic technology to help monitor trees at Soergel Orchards.

Even in this high-tech era, people with bushel baskets still climb ladders to pick the apples we eat.

Manual labor rules the orchard.

And, excuse the apple puns, but the lack of automation has become the orchard industry's core problem. For years, orchard owners have been craving seed technology to juice up profits, ripen yields and peel away labor costs.

So Carnegie Mellon University is trying to polish apple production -- and while they're at it, orange production -- with some robotic technology. Apple and orange growers anxiously await the fruits of their labors.

"Everything is hand labor," said Reed Soergel, whose family owns Soergel Orchards in Franklin Park. "The big question for the industry is, when fruits or vegetables are ready to harvest, you can't take time to find labor.

"Labor is the biggest cost we have," he said. "There's no good way to harvest fresh fruit."

A team led by Sanjiv Singh, a research professor in CMU's Robotics Institute, is using Soergel's as a test site to develop robotic equipment that could offer advantages for orchard keepers.

Another group of researchers at the institute's National Robotics Engineering Center, or NREC, also is busy developing similar technology for orange groves.

The two research groups have received $10 million in grants ($6 million for apples and $4 million for oranges) from the U.S. Department of Agriculture to build automated farming systems.

"We firmly believe the two projects are critical to the viability of farming in the United States," said Herman Herman, a principal commercialization specialist at NREC. "The emphasis is identifying the issues and finding solutions to make this work in the real world."

The goal is affordable robotic technology that can improve fruit quality and lower production costs.

CMU, along with Penn State, Purdue, Oregon State and Washington State universities and various technology companies, have formed a consortium to push fruit production into the modern era.

At Soergel's, the four-wheeled vehicle Dr. Singh is developing features sensors, lasers, cameras, global positioning systems and other technology to be used to monitor tree growth and chlorophyll levels, spot early signs of disease or insect infestation, estimate yields and even determine optimal time for harvest.

In another phase, the technology will be advanced to mow between trees and selectively spray pesticides and herbicides. In
time it could be expanded to include thinning, pruning and harvesting.

The projects were funded this fall through the USDA's new Specialty Crop Research Initiative. Dr. Singh is leading the Comprehensive Automation for Special Crops Program, while Tony Stentz and Dr. Herman at NREC are focusing on citrus.

NREC's Integrated Automation for Sustainable Specialty Crop Farming Project is preparing to deploy a fleet of unmanned tractors to orange groves of Southern Gardens Citrus, one of Florida's largest growers.

Other universities are working on biological improvements, including orchard and grove design.

Soergel Orchards, for example, has begun planting apple trees closer together to create a hedge effect, or wall of fruit, that's even easier to pick. The trees are bred to produce fruit on outside limbs, rather than deep in the tree, to make harvesting easier. "These are not the trees that [Sir Isaac] Newton sat under," Dr. Singh said.

Dr. Herman said the teams will share some technology, but differences, frankly, are apples and oranges. "We hope that within two to three years we have a system working in an actual citrus grove."

Mr. Soergel said "the most exciting part is keeping prices as low as possible and cutting costs" at the orchard his family has operated since 1850. One priority is giving an early alert to growers when insects arrive or disease shows up.

For now, Dr. Singh's team is developing a way for their robotic vehicle to understand where it's situated in the orchard.

Larger orchards already use moving platforms that proceed slowly, tree to tree, and can be raised or lowered depending on the fruit's location. An immediate goal is a platform that travels without a driver.

"We're taking baby steps," Dr. Singh said.

Or, as he notes with a wry smile, "we're picking the low-hanging fruit."

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$9 million for tree fruit research

A project led by Carnegie Mellon focuses on automating orchard tasks.

GERALDINE WARNER

Three research and extension projects designed to improve the competitiveness of the tree fruit industry have together been awarded more than $9 million in grants by the U.S. Department of Agriculture.

A team led by Carnegie Mellon University, Pittsburgh, Pennsylvania, received $6 million to work on comprehensive automation for tree fruits.

Pennsylvania State University is heading a $1 million project exploring innovative technologies for fruit thinning.

And, Washington State University is leading a $2.2 million effort to enhance biological control to stabilize integrated pest management in western orchards.

Those projects were among 17 projects that were awarded a total of $27 million through the Specialty Crop Research Initiative, which was established in the 2008 Farm Bill. The USDA also awarded planning grants for future projects.

"We finally now have an opportunity for specialty crops to compete for funding that's of sufficient magnitude to make a real difference," commented Dr. Jim McFerson, manager of the Washington Tree Fruit Research Commission.

He said the USDA received more than 230 applications for funding and gave preference to projects submitted by multidisciplinary, multiregional, and multi-institutional teams. Matching funding from other sources, including industry, is required.

Extension efforts are an integral part of the tree fruit projects so that industry can benefit quickly from the research, rather than waiting until the research is completed, McFerson said. The projects involve economists, sociologists, and commercial partners, to ensure that the results have measurable impacts on the industry. "Researchers now have an opportunity to participate in a new kind of research that will have a direct impact on stakeholders," he said. "We're taking a different approach. It requires more people, more money, and it's more complicated."

This approach moves beyond looking at problems as uniquely disease problems, or bug problems, or horticultural problems, he said. Collaborators are tackling problems from the point of view of the producer or processor rather than the scientific discipline. Research will be done in commercial orchards, and each of the projects has an advisory panel of industry people.

Ultimately, the projects should help producers grow fruit more efficiently and deliver the best possible product to the consumer in order to generate repeat sales, McFerson said. "It's all about competitiveness. It's to maintain a competitive U.S. specialty crop industry in the global marketplace."

Comprehensive Automation for Specialty Crops ($6 million)

Project leader Dr. Sanjiv Singh at the Robotics Institute of Carnegie Mellon said the goal is to develop an autonomous vehicle that could be reconfigured to perform a number of orchard tasks and
Selected Journal Papers

(First Page)
A Practical Obstacle Detection System for Autonomous Orchard Vehicles

Gustavo Freitas, Bradley Hamner, Marcel Bergerman and Sanjiv Singh

Abstract—Safe robot navigation in tree fruit orchards requires that the vehicle be capable of robustly navigating between rows of trees and turning from one aisle to another; that the vehicle be dynamically stable, especially when carrying workers; and that the vehicle be able to detect obstacles on its way and adjust its speed accordingly. In this paper we address the latter, in particular the problem of detecting people and apple bins in the aisles between rows. One of our requirements is that the obstacle avoidance subsystem shouldn’t add to the robot’s hardware cost, so as to keep the acquisition cost to growers as low as possible. Therefore, we confine ourselves to solutions that use only the sensor suite already installed on the robot for navigation—in our case, a laser scanner, low–cost inertial measurement unit, and steering and wheel encoders. Our methodology is based on the classification and clustering of registered 3D points as obstacles. In the current implementation, obstacle avoidance takes in 3D point clouds collected in apple orchards and generates an off–line assessment of obstacle position. Tests conducted at our experimental orchard–like environment in Pittsburgh and an actual apple orchard in Washington state indicate that the method is able to detect people and bins located along the vehicle path. Stretch tests indicate that it is also capable of dealing with objects as small as 15 cm tall as long as they aren’t covered by grass, and to detect people crossing the aisles at walking speed.

I. INTRODUCTION

Tree fruit production is a very labor–intensive business. In the US, for example, labor account for over 50% of the variable costs to produce apples. Additionally, the number of workers required varies significantly throughout the year—in the state of Washington, for example, it fluctuates between 5,000 workers in the winter time to 35,000 at the peak of harvest. Clearly, there is an opportunity to introduce automation solutions into tree fruit production to lower labor costs, smooth out labor requirements, and increase production efficiency. This opportunity is compounded by the introduction of high–density planting architectures in the past twenty years, where fruit grows along “walls” formed by the branches of trees just four to six feet apart. Autonomous vehicles driving down along these fruit walls can mow and spray, as well as carry workers pruning, thinning, performing tree maintenance, and harvesting.

For the past three years we have been developing a family of such vehicles, which we call Autonomous Prime Movers, or APMs (Figure 1). The current APMs are capable of autonomously driving between a row of trees, turning at the end of the aisle and entering the next one. Row following is conducted at the center of the aisle (e.g., for sensing or mowing) or at a predefined distance from the trunk line (e.g., for pruning, thinning, or spraying). To be affordable to growers, the APMs do not carry a high–accuracy GPS–assisted inertial navigation system (INS), as is usual in agricultural automation. Rather, they navigate using only one laser rangefinder, a low–cost inertial measurement unit (IMU), and steering and wheel encoders.

Between 2009 and 2011 the five vehicles in the APM family drove a combined 330 km in research and commercial orchards in several US states. Preliminary results indicate that workers on an APM–mounted platform can conduct some tasks on the top of the trees in half the time taken by workers on ladders or on foot [7], [8].

While performance when driving between rows is satisfactory, the current system does not include the capability to detect obstacles in the aisle and adjust vehicle speed accordingly. Clearly, this is a safety requirement that must be addressed before APMs can become part of the tree fruit grower toolbox. Additionally, any obstacle detection system must not add to the hardware cost of the vehicle, lest cost issues increase the adoption barrier. Finally, the system must robustly detect the two major obstacles found in orchards: people and bins.

In this paper we address obstacle detection for autonomous orchard vehicles driving at working speeds of up to 1 m/s, using only the sensing suite already in place for row following—namely, a laser scanner, IMU, and steering and wheel encoders. Our methodology consists of four steps:
Monocular Visual Navigation of an Autonomous Vehicle in Natural Scene Corridor-like Environments

Ji Zhang, George Kantor, Marcel Bergerman, and Sanjiv Singh

Abstract—We present a monocular visual navigation methodology for autonomous orchard vehicles. Modern orchards are usually planted with straight and parallel tree rows that form a corridor-like environment. Our task consists of driving a vehicle autonomously along the tree rows. The original contributions of this paper are: 1) a method to recover vehicle rotation independently of translation by modeling the vehicle as a car-like robot driving on a 3D ground surface—the rotation is estimated from monocular images while the translation is measured by a wheel encoder; and 2) a method to fit the 3D points corresponding to the trees into straight lines via an optimization algorithm that minimizes the error variance on the robot lookahead point. Additionally, we use a simple vanishing point detection approach to find the ends of the tree rows. The vanishing point detection is integrated into the system via an extended Kalman filter. The methodology’s robustness to environmental changes is validated in more than fifty experiments in research and commercial orchards, six of which are presented and discussed in detail.

I. INTRODUCTION

This paper focuses on autonomous navigation for orchard applications. As shown in Fig. 1, modern orchards are planted with straight and parallel tree rows. The tree rows are often straight over hundreds of meters, and the space between two tree rows forms a corridor-like environment. The task is to drive a robot autonomously along the tree rows, which requires an approach to continuously estimate the distance and orientation of the tree rows with respect to the robot. Due to different tree types and lighting conditions, the approach has to handle considerable environment variations in both shape and appearance. To keep the system simple and relatively low-cost, a monocular camera is used.

We reconstruct the local structure of the tree rows using image frames and wheel encoder readings. The Ackermann steering model [1] is adopted as the problem constraint. While existing work in visual navigation that uses the robot steering model assumes a flat ground plane, we model the robot as a car-like vehicle driving on a 3D ground surface. By using the Ackermann steering model, we are able to recover the robot orientation separately from the translation. The orientation is estimated with the Singular Value Decomposition (SVD) method [2]. To deal with the scale ambiguity associated with a monocular camera, the translation is measured by wheel encoder reading. The 3D points on the tree rows are reconstructed from the robot motion, and then fitted into straight lines. The line fitting employs an optimization applied to a Random Sample Consensus (RANSAC) [3] algorithm, which minimizes the error variance on the robot lookahead point.

The proposed tree row reconstruction gives a noisy estimation on the tree row orientations. To obtain an accurate estimation on the orientation, a simple vanishing point detection approach is constructed that finds the tree rows’ ends. The vanishing point detection uses the vertical edges on the tree trunks and branches, and finds the point in the image frame where the tree rows vanish. To make the approach robust to lighting condition changes, the edge points are passed through a color filter in $c_1c_2c_3$ space [4]. Then, the two parts of our approach are integrated in an Extended Kalman Filter (EKF) [5].

We conduct experiments with six types of trees, at different orientations and times of day. For each test, the tree rows are over 100 m long. We present field results with the robot autonomously driving over 1.7 km. The results show that our approach is robust to environmental changes, with the crosstrack error with respect to the road centerline at the 10 cm level.

II. RELATED WORK

Research on visual navigation [6] has progressed significantly over the recent decade. Successful applications have been implemented on mobile robots [7], [8], aerial robots [9], [10], underwater robots [11], and even mobile devices [12]. For agriculture applications, vision-based guidance has received large attention [13]–[16]. Most of this work focuses on short crops. Camera images from top-down view are used for detecting the vegetation from ground. Considering that the trees in the orchards are tall and form a corridor-like environment, top-view images are unavailable.
A PRACTICAL LOCALIZATION SYSTEM FOR ORCHARD VEHICLES

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Abstract—This paper addresses the design, development and field-testing of a localization system for agricultural vehicles. The Autonomous Prime Movers (APMs) are electrical vehicles designed to operate in specialty crops, more specifically in orchards. In order to accomplish geo-referenced tasks inside the crops, the vehicles must know their pose with sub-meteric accuracy. One of our requirements is that the localization system shouldn’t add to the vehicle’s hardware cost, so as to keep the acquisition cost to growers as low as possible. Therefore, we confine ourselves to solutions that use only the sensor suite already installed on the robot for navigation - in our case, laser scanners and steering and wheel encoders. The developed localization methodology employs an Extended Kalman Filter. The APM pose is predicted using encoder odometry and updated with point and line features detected with the laser. Tests conducted at our experimental orchard-like environment in Pittsburgh and actual apple orchards in Pennsylvania and Washington states indicate that the localization system is able to estimate the vehicle pose with sub-meteric accuracy.

Keywords—Autonomous Agricultural Vehicles, GPS-Free Localization, Extended Kalman Filter.

Resumo—Este artigo apresenta o projeto, implementação e testes de campo de um sistema de localização para veículos agrícolas. Os Autonomous Prime Movers (APMs) são veículos elétricos projetados para operações em pomares e viveiros. A fim de realizar tarefas geo-referenciadas dentro da plantação, os APMs devem conhecer sua posição com precisão sub-métrica. O sistema de localização não deve adicionar custos ao veículo, de forma a facilitar sua aquisição por produtores agrícolas. Desse modo, o sistema desenvolvido utiliza apenas os sensores já disponíveis no veículo para navegação - no caso, laser scanners e encoders, integrados utilizando um filtro de Kalman estendido (EKF). Testes realizados em pomares comerciais e experimentais demonstram que o sistema de localização é capaz de estimar a posição do veículo de maneira eficiente, e indicam condições de operação onde o sistema apresenta precisão sub-métrica.

Palavras-chave—Veículos Agrícolas Autônomos, Localização sem GPS, Extended Kalman Filter.

1 Introduction

Specialty crops are defined in the US as fruits and vegetables, tree nuts, dried fruits and nursery crops including floriculture. Their market value in 2007 neared US$ 50 billion, or almost 17% of the entire US agricultural market value. In that year, the five largest fruit and tree nut crops (grapes, apples, almonds, strawberries and oranges) brought US$ 11 billion in cash receipts to farmers. Fruit and tree nut production alone generate about 13% of all farm cash receipts in the country (Singh et al., 2010).

There is a great opportunity to introduce automation solutions into tree fruit production to lower labor costs, smooth out labor requirements, and increase production efficiency. This opportunity is compounded by the introduction of high-density planting architectures in the past twenty years, where fruit grows along “walls” formed by the branches of trees just four to six feet apart. Autonomous vehicles driving down along these fruit walls can mow and spray, as well as carry workers pruning, thinning, performing tree maintenance, and harvesting.

The ability to accurately determine the position is a fundamental component to increase productivity in many agriculture applications. Geo-referenced data about the crop can reduce costs by limiting the use of valuable resources. Most of the localization systems used in agriculture are based on GPS (O’Connor et al., 1996). A standard GPS provides accuracy between 2 – 20 m. This precision may be enough for program crops such as corn, soy, and wheat. However, considering specialty crops adopting high density architecture, a sub-meteric localization precision is required. Existing GPS based solutions for high accuracy in field are considerably expensive, and may be prohibitive for small and medium farmers. Other problem related to GPS is the loss of connection, caused when the line-of-sight to the GPS satellites is occluded by trees and other structures.

For the past four years we have been developing a family of vehicles for agricultural automation, which we call Autonomous Prime Movers, or APMs (Figure 1). The current APMs are capable of autonomously driving between a row of trees, turning at the end of the aisle and entering the next one. Row following is conducted at the center of the aisle (e.g., for sensing or mowing) or at a predefined distance from the trunk line (e.g., for pruning, thinning, or spraying). To be affordable to growers, the APMs do not carry a high-accuracy GPS system. Rather, they navigate using only laser rangefinders and steering and wheel encoders.

The APMs must accomplish geo-referenced tasks inside the orchards. Associated to localization, all data acquired by the vehicles sensors can be incorporated into maps composing a geographic information system (GIS) framework. By knowing their pose, the APMs can execute precision missions like spraying and applying inputs only in the required trees.

The role of positioning becomes even more critical in the case of automated or partially-automated vehi-
Automated Crop Yield Estimation for Apple Orchards

Qi Wang, Stephen Nuske, Marcel Bergerman, Sanjiv Singh
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Abstract  Crop yield estimation is an important task in apple orchard management. The current manual sampling-based yield estimation is time-consuming, labor-intensive and inaccurate. To deal with this challenge, we develop and deploy a computer vision system for automated, rapid and accurate yield estimation. The system uses a two-camera stereo rig for image acquisition. It works at nighttime with controlled artificial lighting to reduce the variance of natural illumination. An autonomous orchard vehicle is used as the support platform for automated data collection. The system scans the both sides of each tree row in orchards. A computer vision algorithm is developed to detect and register apples from acquired sequential images, and then generate apple counts as crop yield estimation. We deployed the yield estimation system in Washington state in September, 2011. The results show that the developed system works well with both red and green apples in the tall-spindle planting system. The errors of crop yield estimation are -3.2% for a red apple block with about 480 trees, and 1.2% for a green apple block with about 670 trees.

1 Introduction

Crop yield estimation is an important task in apple orchard management. Accurate yield prediction (by number of apples) helps growers improve fruit quality and reduce operating cost by making better decisions on intensity of fruit thinning and size of the labor force for harvest. It benefits packing industry as well, because managers can use estimation results to have an optimized capacity planning for packing and storage. Typical yield estimation is performed based on historical yields, weather conditions, and measurements manually taken in orchards. Workers conduct manual measurements by counting apples in multiple sampling locations. This process is time-consuming and labor-intensive. The limited sample size is usually not enough to reflect the yield distribution across an orchard, especially
A Safety Architecture for Autonomous Agricultural Vehicles

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Abstract.  Sixty years after debuting in industrial environments, robots are making their way into our everyday life.  Farmers have benefited for some time from self-guided machinery including combines and harvesters. More recently, multi-purpose autonomous vehicles have started to be deployed in orchards, groves, nurseries, and other agricultural environments to automate or augment operations such as pruning, thinning, harvesting, mowing, and spraying.  Successful commercialization of such vehicles will depend heavily on them being able to operate safely and avoid accidents involving humans, animals, trees, and farm infrastructure.

We propose a safety architecture to guide the design and deployment of autonomous agricultural vehicles and their introduction into production environments.  The architecture spans the three elements that, combined, should ensure safe operation over a wide spectrum of applications: (1) a distributed, sensor-based, intelligent decision-making system that coordinates and guides fleets of vehicles in and around orchards and other agricultural environments; (2) multimodal interfaces for workers to interact with the vehicles using natural language, gestures, and portable devices; (3) a comprehensive regulatory framework of standards for vehicle safety that covers everything from basic robotic technology to advanced behaviors.

In this paper we present the fundamental aspects of this agricultural robotic safety architecture.  We illustrate its application with examples of autonomous agricultural vehicles we developed in the past that lay down the path toward full introduction of safe, intelligent machines in agricultural production environments.

Keywords.  Agricultural robotics, Autonomous orchard vehicle, Vehicle safety, Human-machine interface, Standards
Design of Crop Yield Estimation System for Apple Orchards Using Computer Vision

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Abstract. Crop yield estimation is an essential element in apple orchard management. Apple growers currently predict yield based on historical records and manual counting. These methods require extensive experience on the part of farm managers to take into account variations in weather, soil conditions, pests, etc., and are generally labor-intensive and inaccurate. In this work, we propose an automatic computer vision system for detecting and counting red apples to predict crop yield in orchards. The system is composed of a low-cost two-camera rig with ring flashes, and custom computer vision algorithms to process images. The camera rig is mounted on an automated utility vehicle. It acquires images of trees at nighttime using the flashes to avoid unpredictable variations in natural lighting conditions. Our algorithms use color as a visual cue to detect red apples from a tree. Apple detection results and geographic coordinates of the vision system (obtained by GPS) are used to locate and count the fruit. We present here the current system configuration, and its preliminary evaluation on a dataset collected at the Sunrise Orchard in Rock Island, WA, in September 2011.

Keywords. Crop yield estimation, Computer vision, Apple detection.
Results with Autonomous Vehicles Operating in Specialty Crops

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Abstract—Specialty crops constitute a $45 billion/year industry. As opposed to crops such as wheat, cotton, corn and soybean, they are characterized by the need for intensive cultivation. Specialty crops growers currently face serious labor cost and availability problems, and few technological solutions exist to increase their efficiency given the past history of abundant supply of low-cost labor. This leads to an opportunity to use recent technological advances to not only increase efficiency and reduce labor costs in specialty crops production but also to support a domestic engineering solutions industry for specialty crops. We envision a family of reconfigurable vehicles that can be rapidly tasked to automate or augment pruning, thinning, harvesting, mowing, spraying, etc. They would share a common sensing and computing infrastructure, allowing applications created for one to be easily transferable to others—much like software applications today are transferable from one computer to another. In this paper we describe our work over the last three years designing and deploying a family of such vehicles, the Autonomous Prime Movers (APMs). The five vehicles completed so far have traveled autonomously over 300 km in research and commercial tree fruit orchards; preliminary results in time trials conducted by extension educators indicate efficiency gains of up to 58%.

I. INTRODUCTION

SPECIALTY crops (fruits, vegetables, horticulture and floriculture) constitute a $45 billion/year industry. As opposed to crops such as wheat, cotton, corn and soybean, they are characterized by the need for intensive cultivation. The specialty crops industries face serious challenges today. Labor costs have increased from 38% of the net value of the farm economy to 58% in the past decade. Not only is the cost of labor limiting economic returns, but also the seasonal availability and training requirements adversely affect the cost of production. Across the board, specialty crops are facing a crisis of increasing labor costs and shortages of available labor. In addition to labor costs, an increasing consumer demand for a safe, affordable, traceable, and high quality food supply, and the need to minimize the environmental footprint, represent key challenges for specialty crop sustainability in the United States. Given the past history of abundant supply of low-cost labor, few technological solutions to increase production efficiency have been viable. The current climate gives us an opportunity to use recent technological advances to not only increase efficiency in production of specialty crops but also to support a domestic industry in engineering solutions for specialty crops.

While specialty crops as a whole represent a significant market, the needs of specific industries are diverse and there is a lack of common tools. This is as compared to automation for commodity crops for which many operations can be conducted by automating coverage patterns [11]. When the need has been substantial, growers of specialty crops have produced customized tools for specific applications. While some customization is unavoidable, few common building blocks exist that can be used to readily improve efficiency without complete systems development.

One place to look for efficiencies is in the set of tasks such as pruning, thinning, tree training, harvesting, mowing and spraying that must be conducted by vehicles moving at low speeds (typically < 3 km/h) through orchards, vineyards and groves. The state of the art today has been in the development of implements that can be attached to tractors, most of which have been designed for tasks that require much more power. Today, the need is for a generation of nimble, low-cost vehicles that can be easily reconfigured for tasks that require precision rather than brawn. Such vehicles would be up to date with standards in information technology and would fit into the electronic workflow management of crops. The vehicles would reduce the environmental footprint of production, and, most importantly would be both reliable and low-cost taking advantage of large economies of scale.

Consider, for example, the recent study by Baugher [2], who quantified the benefit of mobile platforms in orchards:

Time trials with the moveable platform and ladders were set up so they could be statistically compared. Work efficiency with the platform increased by an average of 13% for tree training, 36% for peach thinning, 50% for apple thinning, 34% for peach pruning, 53% for apple pruning, and 39% for peach harvest—all very rigorous tasks. Work quality with the platform was similar to that with ladders, and workers commented on comfort improvements. [...] Economic savings with the self-propelled platform ranged from $128 to $285 per acre for all tasks except tree training and pruning. [...] Orchard workers also commented [on] inherent savings, such as reduced fatigue.

While orchard platforms have been shown to increase efficiency, they have not seen widespread acceptance partly because they are designed for specific applications and are relatively expensive compared to the benefits accrued. Our goal is to demonstrate feasibility of technologies that will
A Low-Cost, Practical Localization System for Agricultural Vehicles

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Abstract. This paper addresses the refactoring of an agricultural vehicle localization system and its deployment and field-testing in apple orchards. The system enables affordable precision agriculture in tree fruit production by providing the vehicle’s position in the orchard without the use of expensive differential GPS. The localization methodology depends only on the wheel and steering encoders and the laser rangefinder already on the vehicle for row following, thus adding zero hardware cost to the overall setup. It employs an Extended Kalman Filter to integrate the information from the sensors, with the pose being predicted via encoder odometry and updated via point and line features detections. The objective of this paper is to describe the complete refactoring of the initial proof-of-concept localization system, with the goal of making it robust, modular and reusable. Field test results indicate that the final system has sufficient accuracy for deployment of autonomous vehicles in tree fruit orchards.

Keywords: Autonomous Agricultural Vehicles, GPS-Free Localization, Extended Kalman Filter.

1 Introduction

Specialty crops are defined in US as fruits, vegetables, tree nuts, dried fruits and nursery crops, including floriculture. In 2007 they accounted for almost 17% of the US agricultural market, or US$50 billion, with fruit and tree nut production alone generating about 13% of all farm cash receipts [6]. Within specialty crops, tree fruit production is particularly challenged by the large cost of labor and its seasonal needs—for example, seven times more apple orchard workers are needed in the state of Washington during harvest season than during the winter pruning season. Today, there is a real opportunity to introduce automation solutions into tree fruit production to lower labor costs, smooth out labor requirements, and increase production efficiency. This opportunity is compounded by the introduction, in the past twenty years, of high-density “fruit wall” planting architectures.
Automated Crop Yield Estimation for Apple Orchards

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Abstract  Crop yield estimation is an important task in apple orchard management. The current manual sampling-based yield estimation is time-consuming, labor-intensive and inaccurate. To deal with this challenge, we developed a computer vision-based system for automated, rapid and accurate yield estimation. The system uses a two-camera stereo rig for image acquisition. It works at nighttime with controlled artificial lighting to reduce the variance of natural illumination. An autonomous orchard vehicle is used as the support platform for automated data collection. The system scans both sides of each tree row in orchards. A computer vision algorithm detects and registers apples from acquired sequential images, and then generates apple counts as crop yield estimation. We deployed the yield estimation system in Washington state in September, 2011. The results show that the system works well with both red and green apples in the tall-spindle planting system. The crop yield estimation errors are -3.2% for a red apple block with about 480 trees, and 1.2% for a green apple block with about 670 trees.

1 Introduction

Crop yield estimation is an important task in apple orchard management. Accurate yield prediction helps growers improve fruit quality and reduce operating cost by making better decisions on intensity of fruit thinning and size of the harvest labor force. It benefits the packing industry as well, because managers can use estimation results to optimize packing and storage capacity. Typical yield estimation is performed based on historical data, weather conditions, and workers manually counting apples in multiple sampling locations. This process is time-consuming and labor-intensive, and the limited sample size is usually not enough to reflect the yield distribution across the orchard, especially in those with high spatial variability. Therefore, the current yield estimation practice is inaccurate and inefficient, and improving it would be a significant result to the industry.
Preliminary Results with a Vacuum Assisted Harvest System for Apples

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The harvest of specialty crops for the fresh market is labor intensive, and attempts at automation have been less successful than with field crops. Apple harvest is particularly difficult to automate because fruit suffer bruise damage easily. Nevertheless, market, social, and political forces have converged to make mechanical augmentation of harvest essential for the survival of the specialty crop industry in the U.S.

The challenges are enormous, as the constraints on candidate technologies include high performance, low cost, robustness, simplicity, and ease of repair. The opportunities and rewards, on the other hand, are commensurately great. Merely addressing these challenges is already inspiring a new generation of engineers and students to think creatively about problems in agriculture and related fields and to bring engineers and growers together (Kliethermes et al., 2010; Leslie et al., 2008; http://www.cascrop.com/index.php?option=com_content&view=article&id=1521&Itemid=666). Successful development technologies could reinvigorate the specialty crop industry, make it competitive in international markets, and employ segments of the population that have largely been excluded from the labor pool due to physical constraints.

The total value of U.S. specialty crops—$49 billion in sales—now exceeds the combined value of the five major program crops—$45.8 billion in sales (Schmoldt, 2007). However, despite the specialty crop industry’s major contribution to the U.S. economy and the finding that “a secure domestic food supply is a national security imperative,” U.S. specialty crop producers remain vulnerable to the real possibility of being eliminated within the next ten years (Schmoldt, 2007). This crisis stems in large part from dependency on a large seasonal workforce, coupled with increasing labor costs and decreasing availability of agricultural employees. In a socioeconomic technology adoption survey of growers conducted by members of our research team, harvesting was among the highest rated areas of need for advanced technologies to improve precision and efficiency in tree fruit production (Ellis et al., 2010).

Prior Approaches to Addressing Harvest Labor Inputs

Mechanical harvesting machines that utilized mass removal techniques were widely tested in the U.S. in the 1970s and 1980s. The machines were unsuccessful in harvesting fruit for the fresh market due to excessive fruit damage caused during fruit detachment, contact with limbs or other fruit while falling through a three-dimensional tree canopy, and bulk collection procedures (Peterson, 2005b).

Mechanical engineering efforts for specialty crops declined in the 1990s, and the focus shifted to the development of labor platforms for use with planar tree architectures. Fruit were still picked and placed in the bin by hand, but harvest efficiency was increased and fruit quality was similar to that which was conventionally harvested (Baugher et al., 2009a; Schupp et al., 2007). In the late 1990s, engineers began looking at automated bin filling technologies, but early designs resulted in excessive bruising of fruit (Peterson, 2005a). The complex fruit handling and equipment/operator interface was a major obstacle to developing semi-automated harvest systems.

Significant progress has been made on robotic harvest. However, insufficient fruit recovery and difficulties in developing both an end effector and a vision system that performs equal to the human hand and human visual system avert commercialization in the near future (Bulanon and Kataoka, 2010; Sarig, 1993).
Autonomous Mechanical Thinning Using Scanning LIDAR

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Abstract. Hand thinning is a labor-intensive and expensive peach production practice. Mechanical thinning has been shown to be an economical method of reducing thinning cost. However, current mechanical thinning systems applied to perpendicular V systems require the operator to constantly steer the tractor to maintain engagement. This paper presents a system using a LIDAR to sense the canopy and automatically control the position of a modified Darwin string thinner position to maintain engagement. We demonstrate that the automated system is approximately as good as a human at
Autonomous Orchard Vehicles for Specialty Crops Production

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Abstract. Comprehensive Automation for Specialty Crops (CASC) is a four-year project to develop crop intelligence and agricultural automation technologies for the apple and nursery tree industries. Supported by the USDA Specialty Crop Research Initiative, CASC aims at impacting industry where it matters most: increasing production efficiency and reducing labor costs. In this paper we present our most recent results with the Autonomous Prime Movers, a family of reconfigurable vehicles designed to augment or automate a variety of orchard operations. We discuss the modifications made on the first APM to make it robust to uneven terrain and variance in canopy types, along with field tests that totaled 159 km in autonomous orchard driving. We also present the design and initial deployment of two new autonomous orchard platforms.

Keywords. Specialty crops, Efficiency improvement, Labor cost reduction, Crop intelligence, Agricultural automation, Autonomous orchard vehicle, Autonomous orchard platform.
Abstract. Canopy performance, the balance of crop weight and canopy volume, is a key indicator of value in viticultural production. Timely and dense measurement offer the potential to inform management practices and deliver significant improvement in production efficiency. Traditional measurement practices are labor intensive and provide sparse data that may not reflect vineyard variability. We propose and demonstrate a combination of visual and laser sensing mounted on vineyard machinery that provides dense maps of canopy performance indicators. Current industry practice for measuring grape crop weight involves manually counting clusters on a vine with destructive sampling to find the average weight of a single cluster. This paper presents an alternative utilizing vision and laser sensing. We demonstrate use of machine vision to automatically estimate the weight of the crop growing on a vine. Validation of the algorithm was performed by comparing weight estimates generated by the system to ground truth measurements collected by hand. Machine mounted laser scanners provide direct measurement of canopy shape and volume. Validation of the canopy volume measurement is provided by correlation with manually collected dormant vine pruning weight. Attaching these laser and camera sensors to vineyard machinery will allow crop weight and canopy volume measurements to be collected on a large scale quickly and economically. Experiments performed at vineyards growing Traminette and Riesling wine grapes and Concord juice grapes show that we were able to determine both crop weight and canopy volume to within 10% of their actual values.

Keywords. Crop Estimation, Canopy Estimation, Machine Vision, Laser Sensing
Deployment of a Point and Line Feature Localization System for an Outdoor Agriculture Vehicle

Jacqueline Libby and George Kantor

Abstract—This paper presents a perception-based GPS-free approach for localizing a mobile robot in an orchard environment. An extended Kalman filter (EKF) algorithm is presented that uses a wheel odometry prediction step and laser rangefinder update steps. There are two update steps, one that uses measurements to reflective point features and one that uses measurements to linear features formed by tree rows. The features are associated to landmarks in previously surveyed maps. The practical issues of dealing with uncertainty both from the environment and the on-board sensors are discussed and accounted for. The resulting algorithm is demonstrated in over 20km of online operation in a variety of real orchard environments.

I. INTRODUCTION

Localization of mobile vehicles is important in precision agriculture for a variety of reasons. Data collected from these vehicles can be geo-registered into maps, which field managers and scientists can use alike. This allows the same vehicle to return to specific locations and perform tasks such as spraying in a more targeted manner, thereby saving valuable resources. Localization is also critical for automated or semi-automated vehicles that can improve productivity for agricultural applications and fulfill the growing demand for labor.

The use of GPS for localization has many drawbacks for specialty crop settings. In orchards such as the ones used in this work (Fig. 1), the line-of-sight to satellites can get occluded by tree canopies. This occlusion problem does not occur in broad-acre crops, where GPS has been successfully used for many years [1]. Even without signal interference, GPS systems that provide sub-meter accuracy are prohibitively expensive for most specialty agriculture applications. Additionally, GPS does not provide information about the orientation of the vehicle, which is necessary for automated steering, as well as for determining the position of objects observed by vehicle-mounted sensors.

This research is part of the CASC project (Comprehensive Automation for Specialty Agriculture), funded by the USDA, to provide new technologies for specialty crops that are reliable and affordable [2]. Our role is to automate a robotic utility vehicle which can drive up and down orchard rows. The work presented here uses a practical approach to deal with the constraints of our platform and the environment. We use a combination of naturally-existing line features that are formed by the tree rows and a small number of artificial point features. As the robot drives down a straight row, noisy lines fitted to the canopy are used to correct for crosstrack error. Reflective tape placed only at the ends of rows are used to detect point features. These features are used in an extended Kalman filter (EKF) for pose estimate corrections.

The orchards we test in have many environmental challenges (Fig. 1). The rows of trees are called fruit walls, resembling vines that grow along wires. The trees are closely spaced and the trunks have very small diameters, with branches that often hang low to the ground. This environment is carefully engineered to maximize light interception to the canopy. Our robot is limited in what it can sense with its fixed 2D lasers. Tree trunks are narrow and often occluded by leaves, ruling out the possibility of using them as point features. Line features can be fit to the straight rows of trees, but these lines are very noisy due to the organic shape of the canopy.

The work presented here uses a practical approach to deal with the constraints of our platform and the environment. We use a combination of naturally-existing line features that are formed by the tree rows and a small number of artificial point features. As the robot drives down a straight row, noisy lines fitted to the canopy are used to correct for crosstrack error. Reflective tape placed only at the ends of rows are used to correct for downtrack error when the robot nears the end of the row, as well as to correct for error as the robot makes tight turns from one row to the next. This allows the robot to traverse entire orchard blocks, and we demonstrate this with multiple endurance runs, where the robot is running online localization algorithms used as inputs for autonomous navigation.

II. RELATED WORK

Laser localization for autonomous ground vehicles in outdoor environments has made many recent advances. Kelly et. al. [3] use GPS for global pose estimates, and deal with GPS drop-outs by using a suite of sensors for local pose estimates.
Results from Survey Instruments Used to Assess Technology Adoption for Tree Fruit Production

Katie Ellis¹,³, Tara Auxt Baugher¹, and Karen Lewis²

SUMMARY. Advances in horticultural production technology are often hindered by slow grower adoption. Low adoption rates are largely the product of skepticism, which can lead to weaknesses in the commercialization process and affect future research and product development. To better understand industry concerns and design effective outreach methods, an information technology survey was designed as part of the U.S. Department of Agriculture Specialty Crop Research Initiative project titled Comprehensive Automation for Specialty Crops (CASC). This study outlines the survey results from 111 participants at tree fruit meetings in the Pacific northwestern and eastern United States in 2009. Many of the misgivings about new automated technologies, such as equipment cost and reliability of harvest assist, sensor systems, and fully automated harvest machinery, were consistent across the country. Subtle differences appeared between the eastern U.S. and Pacific northwestern U.S. responses, including justifiable equipment price points and irrigation and pest concerns; these are likely attributable to regional differences in climate, operation size and scale, and marketing strategies. These survey data will help the project team better address grower concerns and uncertainty on a regional and national level, thereby improving adoption speed and rates after CASC-developed technologies are rolled out.

Although automated and precision agriculture initially took off in agronomic crops, it has remarkable value for horticultural specialty crops such as tree fruit (Roberson, 2000). High crop value per unit area and crop response to environmental variables make advanced production technology an important prospect. However, agricultural technology often outpaces the readiness of growers. Modern farming is already complex; producers want to try new science and technologies, but they also value simplicity (Kitchen, 2008).

A number of factors can hamper adoption, including overly complex systems, cost, risk aversion, and perceived negative return on investment (Adrian et al., 2005; Koundouri et al., 2006; Reichardt and Jürgens, 2009; Sassenrath et al., 2008). Other factors that work to enhance adoption rates are the following: perceived economic benefits, ease of use, simplicity, and the potential of technology to decrease production risks (Adrian et al., 2005; Sassenrath et al., 2008). Higher education levels are also generally associated with early adoption, though widespread computer use may be diminishing this effect (Adrian et al., 2005).

Llewellyn (2007) reports that the variation in time to adoption is often attributed to differences in knowledge and perception about the relevant advantage of a technology. To reduce the overall time to adoption, it would be useful to identify early adopters (typically 13% of a given grower group). Early adopters are often highly educated or fill a local leadership role; their endorsement can carry weight among the early majority (34%) and late majority (34%) adopters who tend to hedge their bets by obtaining information from them (Lamb et al., 2008). Those who have the least uncertainty about technology, the lowest evaluation costs, and larger farms tend to adopt new equipments and ideas earlier than others (Barrett et al., 2010).

Earlier research shows that it takes roughly 8 years from the time of public research dollar investment to the implementation of technology by early adopters. In the agricultural sector, it can take as long as 15 years before full adoption by stakeholders occurs (Alston et al., 1995). In the realm of automation and precision agriculture, many technologies become obsolete in 15 years, creating a need to increase the speed of adoption.

This is particularly important for successful roll out of new equipment developed as part of recent horticultural technology initiatives. The CASC project is a Specialty Crop Research Initiative program funded through the National Institute of Food and Agriculture, U.S. Department of Agriculture. CASC goals include the development of information technologies that enhance tree fruit crop monitoring, reduce labor, and increase fruit quality and yields. The project also aims to accelerate technology adoption by analyzing its return on investment and identifying and mitigating barriers to adoption.

A CASC socioeconomic survey was drafted in Jan. 2009 to solicit stakeholder input and identify potential obstacles to industry adoption of new automation technologies developed for tree fruit production. The survey tool had 35 questions and a brief explanation of the project and the purpose of the survey. The questions were grouped into seven related sections specific to technologies under development by CASC project leaders: 1) demographic information and farm enterprise specifics; 2) needs/potentials for automation and sensor technologies in specialty crops; 3) potential benefits of harvest-assist (semiautomated harvest) technology; 4) potential benefits of automated
Comprehensive Automation for Specialty Crops: Year 1 results and lessons learned

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Abstract Comprehensive Automation for Specialty Crops is a project focused on the needs of the specialty crops sector, with a focus on apples and nursery trees. The project’s main thrusts are the integration of robotics technology and plant science; understanding and overcoming socio-economic barriers to technology adoption; and making the results available to growers and stakeholders through a nationwide outreach program. In this article, we present the results obtained and lessons learned in the first year of the project with a reconfigurable mobility infrastructure for autonomous farm driving. We then present sensor systems developed to enable three real-world agricultural applications—insect monitoring, crop load scouting, and caliper measurement—and discuss how they can be deployed autonomously to yield increased production efficiency and reduced labor costs.

Keywords Specialty crops · Reconfigurable mobility · Crop intelligence · Insect monitoring · Crop load estimation · Caliper measurement

1 Introduction

Specialty crops are defined in the US as fruits, vegetables, tree nuts, dried fruits, nursery crops, and floriculture. Their market value in 2007 neared $50 billion, or almost 17% of the entire US agricultural market value, up from $41.2 billion in 2002—an annual growth of 3.9% [15]. In 2007, the five largest fruit and tree nut crops (grapes, apples, almonds, strawberries, and oranges) brought $11.0 billion in cash receipts to farmers [8]. Fruit and tree nut production alone generate about 13% of all farm cash receipts in the country.

Especially in the tree fruit industry, labor represents a large percentage of production costs (Fig. 1) and automation is not as widely available as in program crops, such as corn, soy, and wheat. Comprehensive Automation for Specialty Crops (CASC) aims at developing technologies and methods to improve production efficiency and reduce labor costs in the apple and nursery tree industries. The project is based on three main pillars: integration of robotics technology and plant science, overcoming socio-economic barriers that prevent or delay technology adoption by growers, and making the results available to growers and stakeholders through a nationwide outreach program. For a general overview of the project’s goals, we refer the reader to [10].

Central to our work is the development and deployment of automated prime movers, or APMs—a family of reconfigurable robotic vehicles that can autonomously drive in fruit production environments (orchards, groves, vineyards, etc.) and nurseries. The APMs can carry sensors, instruments, farm implements, and even people to automate or augment production operations, including:

- harvesting, pruning, spraying, and mowing;
- plant inspection for stress, disease, and insect detection;
Hyperspectral Image Analysis for Plant Stress Detection

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Abstract. Plant stress significantly reduces plant productivity. Automated on-the-go mapping of plant stress allows for timely intervention and mitigation of the problem before critical thresholds are exceeded, thereby maximizing productivity. A hyperspectral camera analyzed the spectral signature of plant leaves to identify the plant water stress. Five different levels of water treatment were created on young apple trees (Buckeye Gala) in a greenhouse and continuously monitored with a hyperspectral camera along with an active-illuminated spectral vegetation sensor and a digital color camera. Individual spectral images over a 400 – 1000 nm wavelength range were extracted at a specific wavelength to estimate reflectance and generate spectral profiles for five groups of apple

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trees at different water treatment levels. Various spectral indices were investigated and correlated to stress levels. The highest correlation was found with Red Edge NDVI at 705 nm and 750 nm in narrowband indices and NDVI at 680 nm and 800 nm in broadband indices. The experimental results indicate that intelligent optical sensors could deliver decision support for plant stress detection and management.

Keywords. Sensors, illumination, spectral response, measurement, leaves, water stress.
Active Spectral Sensor Evaluation under Varying Conditions

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Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
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Abstract. Plant stress has been estimated by spectral signature using both passive and active sensors. As optical sensors measure reflected light from a target, changes in illumination characteristics critically affect sensor response. Active sensors minimize the illumination effects by producing their own illumination that is reflected from the target and measured by the detector. Although active sensors use modulated radiation that can be differentiated from ambient illumination, in order to validate data and increase the accuracy, sensor performance characteristics must be well understood and examined in different target conditions of plant leaves. The performance of an active NDVI sensor was evaluated to study the effect of: 1) partial canopy coverage, 2) target off-center, 3)
standoff distance, 4) target surface tilting, 5) solar bidirectional effect, 6) temperature, and 7) diurnal radiation change. These evaluations provide a valid range of sensor measurements and a motivation to improve the measurement accuracy by using selective data that can be validated by supplemental sensors.

Keywords. Hyperspectral imagery, spectral response, leaves, water stress, diseases, sensors.
On-the-Fly Tree Caliper Measurement

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Abstract. In fruit and shade tree nurseries, there is a need to count and measure caliper for trees frequently so as to have an accurate inventory sufficiently before harvest since disease, pests and climate can change the yield from year to year. In some tree nurseries it is common practice to count the entire stock three times a year and to caliper them once a year. Both tasks are very labor intensive, involving crews of workers counting trees by hand over several weeks. Experience indicates that caliper and counting millions of trees manually can be error prone. There is a strong need to automate these tasks in the tree nursery industry to decrease labor cost and to improve inventory management. We have developed a device to count trees and to measure caliper while the trees are in the field. The device is designed to be mounted on a carrier passing through rows of trees in a nursery. Tedious tasks are reduced to a simple drive through that could be done simultaneously with tasks such as spraying or mowing. Here we describe the device and results from tests conducted in nurseries in Pennsylvania in 2010. Our experiments show that it is reasonable to expect an accuracy of approximately ±1 mm indoors and ±2.5 mm outdoors.

Keywords. caliper measurement, sensors, inventory management

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Accurate GPS-free Positioning of Utility Vehicles for Specialty Agriculture

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Abstract. This paper presents methods for determining the position of a robotic utility vehicle to sub-meter accuracy without the use of GPS. The approach we use is ideally suited for specialty agriculture applications such as orchards, where commercially available high-accuracy GPS systems are cost-prohibitive and GPS signal interference due to tree canopy can produce unreliable results. Solving the positioning problem provides a foundation for other tasks in precision agriculture that can be conducted with autonomous or partially-automated vehicles. Our algorithms use an Extended Kalman Filter with a suite of sensors. Given an initial estimate of vehicle position, sensors on the wheels and steering linkage are used to predict the path traveled, and then a scanning laser range finder is used to correct this predicted position by measuring the relative position between the vehicle and landmarks in the field. We have experimented with intentionally placed landmarks that use reflective tape, which can easily be identified with the laser. In this paper we present the motivation behind our techniques, the specifics of the algorithms we use, the experimental setups, and the results of field tests conducted during the summer of 2009 from apple orchards in Pennsylvania. Our results provide sub-meter accuracy, and suggest strong promise for reliable localization solutions for commercial applications.

Keywords. Positioning, Precision Agriculture, Autonomous Navigation, Robot Analysis, Specialty Crops
Improving Orchard Efficiency with Autonomous Utility Vehicles

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Abstract. In modern orchards, many maintenance tasks call for a driver to steer a tractor through rows of trees at slow speeds over hundreds of acres as it mows or sprays. Similarly, manually-driven orchard platforms allow a crew of workers to perform tasks such as pruning, training, and thinning. In this paper we report on the development of vehicles capable of autonomous row following in orchards. Such vehicles increase efficiency and reduce production costs by moving a farm worker from an unproductive driving role to a productive one. In the past year, the technologies that enable such autonomous row following have been implemented on an electric utility vehicle capable of continuously driving orchard blocks; to date this vehicle has logged more than 130 km of driverless traversals. The vehicle uses laser range scanners to detect trees and other objects in its vicinity.

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builds a model of the row of trees, and uses this model to safely steer the vehicle along the row without GPS. It detects when it has reached the end of a row, turns, and enters the next row. This way the vehicle can drive entire orchard blocks autonomously, even if the rows are of varied lengths or trees are missing in the rows. In addition to the laser scanners, the only other sensors necessary are wheel encoders that continuously measure distance traveled and the steering angle. All computation is performed on a rugged laptop onboard the vehicle.

We present results of using this autonomous vehicle to tow various types of equipment, mowing an orchard block and spraying weeds. We also show how it was used to deploy a system for apple crop load estimation. Finally, we show how this autonomous navigation technology could aide in thinning, pruning and harvesting by adapting it to a variety of vehicles.

**Keywords.** Agricultural robot, automatic steering, autonomous navigation, specialty crops.
Novel Approaches to Passive Bin Filling for Apples

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Abstract. Bin filling remains among the most challenging operations of apple harvest. The current standard practice is careful release of fruit from the bottom of a picking bag while sweeping the across the top layer of apples already in the bin to distribute the fruit with minimal bruising. This process is time consuming and still prone to damage the fruit. In this paper we describe two new devices that show promise for increasing speed and reducing bruising in passive bin filling. The first distribution is the "energy absorbing grate for apple distribution and bin filling" in which apples are dumped through a network of elastic bands holding energy absorbing foam shapes. The vibration of the elastic bands creates a fluidized bed effect that allows apples to pass through the device while reducing their speed so that bruising is nearly eliminated. The second is the "pneumatic self-adjusting bin filler," in which alternate inflation and deflation of adjacent cylindrical bladders causes the device to climb up the rising pile of apples in the bin filler. The bladders also serve as to absorb the energy of the falling apples. We will present the design process, the results of laboratory and field tests, lessons learned, and future plans.

Keywords. Apple harvest, bin filling, energy absorbing materials.
Selected Posters
## Comprehensive Automation for Specialty Crops | cascrop.com
### Year 3 Achievements & Year 4 Goals


1. **Carnegie Automation**
   - **Adoption**
   - **Intelligence**

### Automation

***DONE:***
- Developed "on-line" localization using the same sensors used in autonomous steering
- Developed "off-line" method that can be used to help register inventories

***TO DO:***
- Redesign vehicle to allow for improved physical controls in field conditions
- Modify to allow for large variations in speeds from .25 mph to 15 mph

#### Reconfigurable Mobility: autonomous vehicles to increase production efficiency

#### Accurate Positioning: low-cost vehicle localization for precision agriculture

#### Augmented Harvesting: systems to reduce labor cost in fruit picking

#### Plant Stress & Disease Detection: preventing loss of fruit-bearing wood

***DONE:***
- Deployed improved digital trap in PA and WA orchards and added GPS-based insect monitoring and graphical user interface
- Detected internal feeding worm damage in apple images with 90% accuracy

***TO DO:***
- Conduct disease prediction studies based on sensor network data and compare to results obtained with weather station-based data

#### Insect Monitoring & Infestation Detection: systems that automatically count insects in the orchard

#### Crop Load Scouting: vision-based systems for accurate, automatic yield estimation

#### Automated Caliper & Counter: measure tree growth & inventory nurseries

***DONE:***
- 96% of the time the error in caliper measurement is less than 2 mm
- Improved counter optics accuracy and maximum speed of travel

***TO DO:***
- Improve caliper performance in the presence of stakes
- Investigate methods to conduct caliper ing and counting in 3D terrain and uneven canopy

### Crop Intelligence

#### Value Proposition: determining feasibility and profitability of CASC technologies

### Adoption

#### DONE:
- Conducted economic analysis for the VRC crop load scout and DBR harvest system
- Conducted AgProfit™ workshops reaching WA & PA growers, lenders, media, educators

#### TO DO:
- Conduct efficiency trials to demonstrate potential impacts from adoption of CASC technologies

#### Outreach: engaging stakeholders early and often

- Trained trainers (extension educators and others) who serve specialty crop growers
- Four field days, 6271 direct contacts, 22 publications, and 4000+ YouTube views

---

2. **22 of different publications, verstakey media, and growers, with the same variety**
3. **VP **
4. **GSC**
Comprehensive Automation for Specialty Crops  | cascrop.com

Year 2 Achievements & Year 3 Goals

Sanjiv Singh1, Tara Baugher2, Marcel Bergerman1, Ben Grocholsky1, Gwen-Alyn Hoheisel2, Larry Hull2, Vincent Jones3, George Kantor1, Harvey Koselka4, Karen Lewis5, William Messner1, Henry Ngugi5, James Owen Jr.5, Johnny Park6, Clark Seavert5, Irene Yung5
1Carnegie Mellon University, 2The Pennsylvania State University, 3Washington State University, 4Vision Robotics, 5Oregon State University, 6Purdue University

Automated Counter

ACCOMPLISHED:
- High accuracy in caliper measure and tree counting in commercial nurseries
- Fast speed of counting

TO DO:
- High accuracy in caliper measure and tree counting in commercial nurseries
- Fast speed of counting

Augmented Harvesting

ACCOMPLISHED:
- Develop “how to” video on passive bin fillers
- Increase harvest efficiency by 25% with vacuum assist system

TO DO:
- Incorporate positioning algorithm in all regular robot operations
- Achieve <0.5 m error 99% of the time

Sociological Implications

ACCOMPLISHED:
- 85% rate of adoption of new tree systems for automation based on field day surveys
- Management efficiency increased 78% in targeted weed application trials

TO DO:
- Adapt Competitive Orchard Sys. DVD for web
- Conduct educational programs and efficiency trials to prepare stakeholders to adopt CASC technologies

Socioeconomic Analysis

ACCOMPLISHED:
- 5% increase in growers’ support in participation, interest, matching funds
- Publication of survey results in refereed journal indicating bi-coastal priorities

TO DO:
- Conduct case studies comparing impacts on small vs. large farms
- Collect adoption rate data, solicit comments about CASC equipment value and usability

Outreach and Extension

ACCOMPLISHED:
- Market assessment of digital insect trap
- Trained PNW and PA growers in AgProfit

TO DO:
- Conduct market assessments of crop load scouting system, tree counter, and harvest assist system

Information Management

ACCOMPLISHED:
- Deployment on APM field testing
- Map of 10 km block with 3 complementary sensors

TO DO:
- Create maps with insect monitoring data
- Publish demo tool for team use

Insect Monitoring and Infestation Detection

ACCOMPLISHED:
- On-the-go multimodal sensing system for plant stress detection
- Found canopy temperature to be a possible early indicator of water stress

TO DO:
- Continue trap testing in commercial settings and increase performance
- Increase IFW detection rate to >90% accuracy with <3% false alarms

Plant Stress and Disease Detection

ACCOMPLISHED:
- Digital trap trial capture rate nearly standard
- Spun-off company to commercialize traps
- Latest IFW damage detection algorithm >80% accuracy with <4% false alarms

TO DO:
- Speed up processing towards real-time
- Determine minimum sample size needed for accurate estimation

Crop Load Scout

TO DO:
- Convert current multimodal sensing system to a low-cost, real-time system
- Investigate plant temperature response to a fire blight strike

Accurate Positioning

ACCOMPLISHED:
- Self-steered over 160 km
- Improved reliability in narrow, hilly rows
- Integrated with platform vehicle

TO DO:
- Develop grower-friendly user interface
- Conduct pruning, thinning, and tree training trials in commercial pilot orchards

Reconfigurable Mobility

ACCOMPLISHED:
- Sub-meter accuracy
- Reduction in number of artificial landmarks required for localization

TO DO:
- Trials of vacuum assist system improved harvest speed >10%, reduced bruising 5%
- Passive bin filler that reduces bruising
A Novel Automated Trap Design
Developed from Initial Tests of Codling Moth and Oriental Fruit Moth Traps

Brian Lehman1, Larry Hull1, Vince Jones2, Johnny Park3, German Holguin3, and Katie Ellis4

Abstract
Insect monitoring can provide valuable information about orchard pest populations, allowing for better timing and/or reduced pesticide costs. However, pest traps must be checked frequently to monitor population dynamics and determine economically-damaging insect population densities. Automated insect traps have the potential to reduce labor costs as well as increase accuracy and timeliness of insect counts.

The current trapping systems for codling moth, Cydia pomonella (L.), and oriental fruit moth, Grapholita molesta (Busck) are based on orange or white large plastic delta traps. Orange traps are replacing the white traps because they tend to capture fewer non-target insects; making it easier to count the traps. Unfortunately, the delta traps are not directly amenable for use in electronic traps, since their shape would make the sensor web geometry overly complex. However, the use of bucket-style traps could simplify the design of a sensor web and allow internal housing for the electronics package.

Our studies were initiated to determine the efficiency of the bucket traps compared to the standard delta traps and evaluate how trap color affected the capture of non-target insects large enough to trip the sensor grid. Trapping records from standard delta traps (orange, white, or clear) were compared to those from bucket style funnel traps (orange, white, or green). The capture rate from the bucket traps was lower than that from the delta traps in all but one trial. Orange bucket traps generally attracted more codling and oriental fruit moths than the other bucket colors; therefore, the orange bucket trap was selected for the electronic prototype.

Fifteen prototypes—each equipped with a micro-controller and infrared sensors for detection of insects passing through the funnel—were tested. Prototype capture rates were low, probably due to deterring ultrasonic waves emitted by the clock crystal of the micro-controller. False capture events were also recorded, possibly during extra flights up and down the trap funnel as the insecticidal kill strip slowly took effect.

Fig. 1. Delta- and bucket-style trap colors tested.

Materials and Methods
Five different trap combinations were tested for both codling moth (CM) and oriental fruit moth (OFM) in Biglerville, PA (Penn State University [PSU]), and for only CM in Quincy, WA (Washington State University [WSU]): two delta-style traps without either orange or white (current standards), and three bucket style funnel traps with either orange, green, or white (Fig. 1). A clear acetate trap was also tested at WSU. All traps were checked weekly; moth and non-target insect species were recorded.

Fifteen electronic prototype traps were also tested at PSU and WSU. These were developed by engineers at Purdue University using commercially available bucket traps and a micro-controller unit powered by AA-type alkaline or NiMH rechargeable batteries (Figs. 2 & 3). Four infrared (IR) emitters and four IR detectors lining the bucket trap funnel allowed for detection of insects passing through the funnel. Traps were also equipped with an external real-time clock that enabled users to set start and end operating times to reduce false positive counts from non-target insects and conserve battery power. The electronic trap prototypes were tested in the field with standard (control) bucket traps in order to compare moth capture rates.

Fig. 2. Internal diagram of automated bucket trap.

Results
- White bucket and white delta traps caught the most large non-target insects.
- In PA, the CM and OFM capture rate of the green and orange buckets was approximately 80% lower than the respective delta traps.
- The orange bucket trap captured a similar or greater number of CM and OFM adults than the other bucket colors, so it was selected for the automated prototype.
- Ultrasonic waves produced by the clock crystal of the micro-controller are suspected of deterring the moths, particularly CM, as they approach the trap.
- False capture events were often recorded when moths entered the trap and flew across the sensors multiple times before the kill strip took effect.

Acknowledgments
The authors wish to acknowledge the funding for portions of this study from the USDA Specialty Crop Research Initiative to Carnegie Mellon University (lead institution) for the Comprehensive Automation for Specialty Crops project.

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Performance of Energy Absorbing Materials for Passive Bulk Bin Filling

Two concepts for achieving the desired functionality of a passive bin filler are (1) grates of granular materials that absorb energy while still allowing fruit to pass through them, and (2) mats of energy absorbing foams. These mats could be used in combination with a grate and would cover any hard materials within the device.

Six configurations of energy absorbing grates were tested by dropping apples through them onto a layer of stationary apples. The performance of these grates was evaluated with respect to bruise width, depth, and volume, and each proved capable of significantly reducing the chance of bruising.

Three different foams were evaluated by dropping apples from various heights onto small samples covering a piece of wood. Bruising was negligible until the threshold height of just under 1 meter (39 inches).

### Effects of energy absorbing grates on apple bruising

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Downgraded to Fancy Grade (%)</th>
<th>Downgraded to Utility Grade (%)</th>
<th>Bruise width (mm)</th>
<th>Bruise volume (mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard foam balls</td>
<td>2 a</td>
<td>0 a</td>
<td>3.1 a</td>
<td>15.7 a</td>
</tr>
<tr>
<td>Soft foam balls</td>
<td>3 a</td>
<td>0 a</td>
<td>2.5 a</td>
<td>12.2 a</td>
</tr>
<tr>
<td>1 layer cork type</td>
<td>3 a</td>
<td>0 a</td>
<td>3.0 a</td>
<td>19.2 a</td>
</tr>
<tr>
<td>2 layers rubber bands</td>
<td>0 a</td>
<td>0 a</td>
<td>3.5 a</td>
<td>8.3 a</td>
</tr>
<tr>
<td>2 layers cork = 1 layer</td>
<td>0 a</td>
<td>0 a</td>
<td>0.8 a</td>
<td>3.8 a</td>
</tr>
<tr>
<td>3 layers cork = 2 layers</td>
<td>0 a</td>
<td>0 a</td>
<td>1.8 a</td>
<td>43.5 a</td>
</tr>
</tbody>
</table>

**Note:** Means with different letters are significantly different according to Fisher's protected least significant difference test (P < 0.05).

### Effects of dense foam materials on bruise volume

A full scale bin filling device, including a method for raising it through the bin will be used in field trials in Fall 2009. Further bruise testing will be conducted to determine the true potential of energy absorbing materials for improving fruit harvest.
Evaluation of Sensor Technologies for Targeted Weed Applications

J. Schupp, T. Baugher, T. Kon, R. Rohrbaugh, R. Hilton, E. Winzeler, R. Dise, A. Jarvinen, C. Kuntz, J. Rouzer

How the Technology Works

- A LED light source projects light onto the ground
- Light that is reflected from the target is captured by a detector
- A sensor recognizes the chlorophyll signature of green plants
- If a green plant is present, a solenoid valve is triggered, activating the nozzle

Objectives

- Quantify efficacy
- Determine chemical and dollar savings

Efficacy of targeted vs broadcast spray applications.

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Pre-application</th>
<th>Post-application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(% of five weeds)</td>
<td>(% of five weeds)</td>
</tr>
<tr>
<td>Orchard A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low weed density, targeted</td>
<td>12 b*</td>
<td>4 bc</td>
</tr>
<tr>
<td>Low weed density, broadcast</td>
<td>15 b</td>
<td>2 c</td>
</tr>
<tr>
<td>Medium weed density, targeted</td>
<td>43 a</td>
<td>11 a</td>
</tr>
<tr>
<td>Medium weed density, broadcast</td>
<td>42 a</td>
<td>7 ab</td>
</tr>
<tr>
<td>Orchard B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low weed density, targeted</td>
<td>9 b</td>
<td>2 a</td>
</tr>
<tr>
<td>Low weed density, broadcast</td>
<td>10 b</td>
<td>1 ab</td>
</tr>
<tr>
<td>Medium weed density, targeted</td>
<td>29 a</td>
<td>2 a</td>
</tr>
<tr>
<td>Medium weed density, broadcast</td>
<td>26 a</td>
<td>1 ab</td>
</tr>
<tr>
<td>Orchard C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low weed density, targeted</td>
<td>8 bc</td>
<td>3 a</td>
</tr>
<tr>
<td>Low weed density, broadcast</td>
<td>6 c</td>
<td>1 ab</td>
</tr>
<tr>
<td>Medium weed density, targeted</td>
<td>13 ab</td>
<td>3 a</td>
</tr>
<tr>
<td>Medium weed density, broadcast</td>
<td>18 a</td>
<td>3 a</td>
</tr>
</tbody>
</table>

*Means separation within columns and ordered by Fisher's protected least significant difference at P=0.05.

Water usage in low or medium weed density plots and associated herbicide savings.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Gallons/ treated</th>
<th>Savings</th>
<th>Cost/ treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (15%) weed density, targeted</td>
<td>15 a</td>
<td>67</td>
<td>14.08</td>
</tr>
<tr>
<td>Low (15%) weed density, broadcast</td>
<td>45 a</td>
<td>67</td>
<td>42.67</td>
</tr>
<tr>
<td>Medium (40%) weed density, targeted</td>
<td>31 b</td>
<td>32</td>
<td>29.01</td>
</tr>
<tr>
<td>Medium (40%) weed density, broadcast</td>
<td>45 a</td>
<td>32</td>
<td>42.67</td>
</tr>
</tbody>
</table>

*Herbicide savings based on water use comparison trial, with WeedSeeker® calibration vs. broadcast in Orchard A plots (see Table 1).

Improving calibration based on grower input.

Special thanks to our friends at the Carnegie Mellon University Robotics Institute: Sanjiv Singh, Marcel Bergerman, Ben Grocholsky

Funding provided by USDA CSREES Specialty Crop Research Initiative for Comprehensive Automation for Specialty Crops
Augmented harvest system for the apple industry that handles the fruit from the time it is picked from the tree until it is placed in the bin. The system is composed of two main components. The first is a vacuum-assisted tube that "sucks" in the apple from the picker's hand and transports it to a location just above the bin, where the fruit arrives with near-zero speed. The second element is an "elephant ear"-type revolving helix that places the fruit one by one in the bin. By eliminating the filling up and subsequent emptying of the picking bag, the system increases harvest efficiency significantly, and by eliminating the dumping of entire bags in the bins, the system helps reduce fruit bruising. The components are modular and can be modified for use with a tractor or another type of orchard platform. Stay tuned for a demonstration during apple harvest!

Funding from the USDA Specialty Crop Research Initiative with matching support from Pennsylvania producers and the State Horticultural Association of Pennsylvania.
Pilot Orchards Provide Laboratories in the Field to Increase Industry Adoption of Labor Assist and Precision Technologies

T. Baugher1, J. Schupp1, K. Lewis2, G. Hoheisel3, K. Ellis1, J. Yung1, F. Winkler1, J. Remcheck1, Alex Leslie1, T. Kon1
1Penn State University, 2Washington State University
USDA Specialty Crop Research Initiative Comprehensive Automation for Specialty Crops

Abstract. A trans-disciplinary team of engineers, plant scientists, ag economists, and extension educators initiated a multi-state project in 2009 to work cooperatively with specialty crop growers to develop engineering solutions to increase production efficiency, environmental sustainability, and social responsibility in orchard systems. Commercial pilot orchards are serving as field laboratories for growers and scientists on new orchard designs for increasing opportunities for automation and precision technologies. The system model being tested in the pilot orchards incorporates a number of best management practices. Trees are trained at high densities on wire trellises to allow for harvest optimum sunlight. The tree design also is very adaptable to new sensor and labor assist technologies. Labor assist technologies that are being tested in the pilot orchards include autonomous work platforms and augmented harvest. Precision technologies being evaluated include targeted application of crop protection sprays. GPS guidance technologies were assessed during planting for increasing accuracy and decreasing labor requirement in laying out uniform orchard rows required for adaptation of precision technologies. Data from the pilot orchards are used to develop a fuel efficiency calculator to assist growers in assessing factors related to the adoption of new technologies.

Precision Technologies for Targeted Application of Crop Protection Sprays
Data from targeted spray application trials indicated the potential to reduce crop protection chemicals by 50 to 75%.

Autonomous Work Platform with Harvest Assist Technologies for Increasing Labor Efficiency
Trials were conducted to compare harvest and pruning from a semi-autonomous platform versus from ladders, and efficiency increased by 45% and 76%, respectively. Carnegie Mellon engineers added sensor technologies that will be tested in 2010. A commercial partner is adding a vacuum fruit transport system and bin fillers.

CAD Illustrations of Tree Training Systems Compared in 12 Commercial Pilot Orchards

Vertical Axis System
Conical tree architecture with demonstrated performance in maximizing sunlight interception

Modification of Vertical Axis under Trial for Automation
Continuous canopy that is more narrow at the top to permit sunlight interception

GPS Guidance System Evaluated to Increase Planting Uniformity
Prior to planting pilot orchards, a tractor equipped with a GPS steering system was used to mark tree rows with a subsoiler. Rows were made on 16 ft centers at speeds of 1.2, 2.0, and 3.0 mph as well as on slopes of 0-3%, 8-16%, and 16-21%. The average deviation from the center at points within the row was 4.2 inches. There was no difference in accuracy at different speeds, but the system was less accurate on steeper slopes and at the beginning of each row.

Energy Efficiency in High Density Pilot Orchards
An energy calculator designed to assess the amount of fuel used for the high density pilot orchards compared to conventional plantings demonstrated that smaller tractors and implements can result in a 25 to 45% reduction in fuel usage.

Acknowledgements
Grant Support – USDA Specialty Crop Research Initiative, USDA NRCS Conservation Innovation Grant, State Horticultural Association of Pennsylvania, Penn State College of Agriculture, Hoffman Foundation
Dr. Comprehensive Automation for Specialty Crops (CAS) Project Team Members: (E. Tingle – Project Leader; M. Bergerman, Project Manager)
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Dr. Comprehensive Automation for Specialty Crops (CAS) Project Team Members: (E. Tingle – Project Leader; M. Bergerman, Project Manager)

Student interns: J. Koen, C. Kertz, E. Mogre, C. Musselman, A. Leslie, A. Jaworski Special Thanks – P. Kohlsbach
Graduate Student: R. Dills, T. Kon

Sample Calculations (10 Acres)

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>High-Density</th>
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<tbody>
<tr>
<td>Gallons Per Year</td>
<td>$1,038.83</td>
<td>$654.75</td>
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<tr>
<td>Cost Per Bushel (500 Bushels)</td>
<td>$8.31</td>
<td>$8.06</td>
</tr>
<tr>
<td>Total</td>
<td>$8,999.80</td>
<td>$4,751.33</td>
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</table>

Thank you!
Publications, progress reports, presentations, workshops, tours, and field days


**Listed as Number 1 read article for April 2010.**


Sanjiv, Sanjiv, Marcel Bergerman, Jillian Cannons, Benjamin Grocholsky, Bradley Hamner, German Holguin, Larry Hull, Vincent Jones, George Kantor, Harvey Koselka, Guiqin Li,


Invited Presentations


Mid-Atlantic Young Grower Alliance. 2009. Investigating New Technologies at Interpoma (panel discussion). Mid-Atlantic Fruit and Vegetable Convention, Hershey, PA.


L. Hull. 2009. Advanced Approaches to IPM (included explanation of automated scouting research). President’s Day Fruit Growers Educational Meeting, Biglerville, PA.

J. Travis, H. Ngugi, N. Halbrendt. 2009. Disease Management—A 5-Year Strategic Plan (included explanation of sensor network research). President’s Day Fruit Growers Educational Meeting, Biglerville, PA.


K. Ellis and J. Remcheck. 2009. Impact of Specialty Crops Innovations Initiative on the Adams County Fruit Belt. Gettysburg and Adams County Chamber of Commerce Agriculture Committee Meeting, Gettysburg, PA.


P. Heinemann and J. Schupp. Innovative Technologies for Peach Thinning. Mid-Atlantic Fruit and Vegetable Convention, Hershey, PA.

T. Baugher. 2010. Results from 2009 Thinning Trials. Mid-Atlantic Fruit and Vegetable Convention, Hershey, PA.


J. Schupp. 2010. Preparing for Orchard Mechanization. International Fruit Tree Association Conference, Grand Rapids, MI.

L. Hull. 2010. Taking IPM to the Next Level (included explanation of information-driven systems and new tools for monitoring). President’s Day Fruit Growers Educational Meeting, Biglerville, PA.
Ellis, K. and N. Halbrendt. 2010. PSU Pest and Weather Alert Systems (included preliminary information that relates to sensor networks). President’s Day Fruit Growers Educational Meeting, Biglerville, PA.


M. Bergerman. 2010. Innovations in Crop Intelligence and Agricultural Automation for Tree Fruit Production (Round Table). Ontario Fruit and Vegetable Convention, Brock University, St. Catharines, Ontario.


J. Schupp, T. Baugher, E. Winzeler, J. Remcheck. 2010. Training Systems for Early Peach Production and Increased Opportunities for Automation. Penn State Fruit Research and Extension Center Technology Showcase, Biglerville, PA.

K. Ellis. 2010. Surveys to Increase Adoption of New Technologies. Penn State Fruit Research and Extension Center Technology Showcase, Biglerville, PA.


P. Brown and J. Schupp. 2011. Encouraging Results from CASC Harvest Assist Trials with a Commercial Partner. Mid-Atlantic Fruit and Vegetable Convention, Hershey, PA.


J. Schupp. Peach Training Systems for the Mid-Atlantic. Mid-Atlantic Fruit and Vegetable Convention, Hershey, PA.


C. Seavert. 2011. Are You Playing to Win or Playing Not to Lose. International Fruit Tree Association Convention, Pasco, WA.

C. Seavert. 2011. Agricultural Economics: Sustaining Profits, Controlling Expenses (interactive Turning Point discussion). International Fruit Tree Association Convention, Pasco, WA.


C. Seavert. 2011. Knowing When Technology is the Right Choice for Your Nursery Farwest Horticulture Convention, Portland, OR.

M. Bergerman. 2011. Developing and Managing a Large SCRI grant. Invited seminar at Michigan State University, Lansing, MI.

M. Bergerman. 2011. Developing and Managing a Large SCRI grant. Joint SAAESD & ASRED Spring Meeting, Greenville, SC.

S. Singh. 2011. Working on Collaborative Projects. 16th Biennial Research Symposium of the Association of 1890 Research Directors, Atlanta, GA.


T. Baugher. 2012. Mechanization Research in the USA. International Fruit Tree Association Annual Conference. Santiago, Chile.


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**TRADE MAGAZINE AND NEWSPAPER FEATURE STORIES**


Tender Fruit Grape Vine, September/October 2008. “Reducing Labour in the Orchard” by Ken Slingerland

Pennsylvania Ag Connection, October 2008. “USDA Awards Over $28 Million in Specialty Crop Research” by USDA.


Peach Fuzz, October 2008 USDA Awards More than $28 Million in Specialty Crops Research by California Canning Peach Association.


Good Fruit Grower, December 2008. “Versatile Robotic Scout should be able to Detect Pests and Diseases and Estimate the Crop, as well as Guide Robotic Pruners and Harvesters” by Geraldine Warner.


Cling Peach Review, Fall 08/Winter 08. “A Time for Innovative Thinking—All Segments of Peach Industry Excited by Innovative Mechanization Research” by Ann Schmidt-Fogarty.


American/Western Fruit Grower, February 2009. “Tree Fruit: Precision Ag Coming Into Focus” by Jim McFerson. (alsoon growingproduce.com)

Lancaster Farmer, February 2009. “New Orchard Technologies Emerging – Apple Tour in Italy, Orchard Robotics are Topics at Convention.”


Penn State College of Agricultural Sciences Dean’s Blog, July 2009. “Our Land Grant Bears Fruit” by Bruce McPheron.


Good Fruit Grower, October 2009. “Ready for Robots? New Technologies will Improve Orchard Efficiency, but will your Orchard be able to Accommodate them?” by Geraldine Warner.

Peach Times, Fall 2009. “What’s Next? Thinning Technology Shows Promise for U.S. Peach Production” by Katie Ellis and Jim Remcheck.


PrecisionAg Works, November 2009. “Tree Fruit: Precision Ag Coming into Focus,” by Jim McFerson.

Penn State College of Agriculture Magazine, Fall 2009. “Fruitful Endeavor – Biological Engineering Students Take Talents to Orchards.”


American/Western Fruit Grower, June 2010. “Welcome to the Machine – Apple Growers are Closer than Ever to Having an Automated Harvesting System suitable for their Needs,” by Brian Sparks.


Good Fruit Grower, August 2010. “Electric Farm Vehicles,” by Geraldine Warner. (Circulation – 11,000)


Good Fruit Grower, September 2011. “The Future is Here – Technology Designed to Automate Various Aspects of Fruit Production will be on View at a WSU Field Day,” by G. Hoheisel.

Good Fruit Grower, October 2011. “New Orchard Technologies are Coming,” by M. Hanson.


American/Western Fruit Grower, March 2012. “Applying Precision Ag to Tree Fruit,” by J. McFerson.


American/Western Fruit Grower, April 2012. “From the Ground Up,” by B. Sparks.


KEPR-TV, September 2012. “Robots replacing fruit pickers? Not quite, but a new machine is changing the industry” by Melanie Tubbs


**BULLETINS, FACT SHEETS, COMPUTER SOFTWARE AND VIDEOS**


Workshops, Tours, Field Days, and Reports to Grower Organizations


November 6, 2008 – Engineering Solutions Tour – T. Baugher, H. Ngugi, and grower representatives Joy Cline, Sergio Aguilar (CASC advisory panel member), Chris Baugher, Neil Starner, Corey McCleaf, Phil Baugher, John Rice, Daniel Rice, Lee Showalter, and Bruce Hollabaugh hosted the Carnegie Mellon SCRI-CASC team of engineers for tours/discussions of vertical axis orchard systems, work platforms, mechanical thinning, GPS guided planting, fruit handling systems, and automated nursery tree caliper measurements.

November 6 – 12, 2008 – Engineering Solutions Tour – K. Lesser, J. Schupp and 9 growers traveled to Bolzano, Italy to attend Interpoma – an international tradeshow on the production, storage, and marketing of apples. Vendors included: nursery companies; tree training, support system, and hail net providers; manufacturers of orchard platforms, mowers, sprayers, tractors, and mechanical thinners; chemical companies; packing line and cold storage facilities; businesses for marketing and packaging solutions. After the tradeshow, the group visited two apple orchards in the South Tyrol region of Italy, and then traveled to the Bodensee region of Germany. The European growers were innovative – having high density tall slender spindle trees and using new technologies such as orchard/harvest assist platforms, tunnel and tower sprayers, and advanced IPM practices. They also visited a packing facility which packs and sells Kiku apples, and the Bodensee tree fruit research station.
November 13, 2008 – Report for Funding Agency – T. Baugher, R. Crassweller, and J. Travis met with the State Horticultural Association of Pennsylvania Board of Directors and provided an update on the three SCRI grants received by Penn State.

November 17, 2008 – PA Pilot Orchard Session at Penn State Fruit Research and Extension Center – J. Schupp, R. Crassweller, J. Halbrendt, T. Baugher, and K. Lesser provided training on advanced IPM strategies for orchard floor management and wildlife control, minimal pruning strategies to reduce labor requirements, and tree architectures for automation observed during a Mid-Atlantic Young Grower Alliance Tour of Italian and German orchards.

November 18, 2008 – Mid-Atlantic Young Grower Alliance Tour of Intensive Fruit Production Systems – T. Baugher, A. Michael, L. Kime, and growers Aimee Rohrbaugh, Dave Musselman, Sidney Kuhn, Dave Kuhn, Mary Margaret Kuhn, Tom Child, and Michael King provided training on risk management, precision agriculture technologies, and tree architectures for automation.

November 30, 2008 – Engineering Solutions Tour – T. Baugher and Interpoma tour representatives K. Lesser, Eddie Rankin, and Megan Rankin hosted a dinner discussion/slide presentation on innovations observed at Interpoma for a delegation from Western New York growers/educators.

December 1, 2008 – Engineering Solutions Tour – T. Baugher, K. Lesser, L. Hull, H. Ngugi and grower representatives Maggie Reid, John Baugher, and Bruce Hollabaugh hosted a comprehensive automation/innovative thinning tour for two Cornell extension educators and four New York growers.


December 17, 2008 – Report for Funding Agency – J. Schupp, J. Travis, and T. Baugher met with the State Horticultural Association of Pennsylvania Extension Committee and provided an update on the three SCRI grants received by Penn State.

December 18, 2008 – Report for Stakeholder Group – P. Heinemann, J. Schupp, T. Baugher, L. Hull, R. Marini, R. Crassweller, and K. Lesser met with the Ag Innovations Advisory Committee and provided an update on the three SCRI grants received by Penn State.

January 28, 2009 – In-Depth Workshop on Tree Architectures for Automation – T. Baugher, J. Schupp, R. Crassweller, R. Marini, and CIG growers Neil Starner, Corey McCleaf, Justin Weaver, and Bill Gardenhour conducted an indepth workshop on tree architectures adaptable to orchard automation. Ninety growers attended the workshop, and 140 workshop notebooks were distributed. Workshop participants were surveyed via Survey Monkey and 78% indicated they learned a great deal about new strategies of pruning for efficiency in intensive fruit plantings. Also 78% are making the following plans as an outcome of what they learned at the
workshop: 1) planting new competitive orchard systems at higher tree densities, 2) establishing new competitive orchard support systems, and 3) adopting peach pruning and training strategies for targeting fruit size and yield. As a result of attending the workshop, 88% rated their level of comfort with transitioning to high value cultivars planted in competitive orchard systems as “very comfortable.”

February 3, 2009 – Advisory Panel Meeting in Conjunction with Mid-Atlantic Fruit and Vegetable Convention – CASC project leaders shared progress with Advisory Panel members and Pilot Orchard cooperators.

April 22, 2009 – Field Demonstration – J. Schupp, T. Baugher, K. Ellis, S. Miller, J. Remcheck, and Grower Cooperators J. Cline, E. Haller, and K. Lesser conducted a mechanical thinning open house –“Spotlight on Mechanical Thinning.” Thirty growers and extension professionals attended from PA, NJ, Ontario, Nova Scotia, and MD. Participants observed the new PT 250 dual string thinner thinning an open center peach orchard, the Darwin 300 vertical string thinner in a perpendicular V orchard, and the new USDA peach drum shaker thinning a perpendicular V orchard.

April 22, 2009 – Field Demonstration – K. Lewis conducted a mechanical thinning open house at Valicoff orchards, Sunnyside, WA for 67 participants.


June 2, 2009 – Classroom in the Field at Hollabaugh Orchards Conservation Innovation Grant (CIG) planting for 50 growers – J. Schupp, R. Crassweller, T. Baugher, L. Hull, and H. Ngugi discussed advanced integrated orchard management strategies and two tree architecture systems for adaptability with automation.

June 25, 2009 – Engineering Solutions Field Day at C&G Orchards and Penn State FREC for 20 growers – Carnegie Mellon, USDA-ARS Appalachian Fruit Research Station, Purdue University and Penn State engineers and plant scientists demonstrated SCRI Comprehensive Automation strategies including autonomous row following, stress sensing, localization, autonomous spraying and mowing.

June 25, 2009 – Cherry Day at Washington State University Prosser Research and Extension Center. G. Hoheisel and K. Lewis organized a field day for 90 growers and allied industry members that included a discussion on mechanical harvest for stem free cherries, worker augmentation, mechanical thinning and over the row platforms.


August 2-4, 2009 – One Year into It: Engineering Solutions for PNW Specialty Crops – C. Seavert, K. Lewis, S. Singh, and P. Heinemann led strategic planning sessions on utilizing engineering technologies to address challenges faced by Pacific Northwest Specialty Crop industries.

August 3, 2009 - One Year Into It: Engineering Solutions for PNW Specialty Crops, Current activities in Building Engineering Capacity in the PNW nurseries presented by J.S. Owen in Wilsonville, OR to 65 growers, allied suppliers, and colleagues.


September 21-22, 2009 – Two-Day Meeting with USDA-SCRI Administrators – P. Heinemann presented first year results from the Innovative Thinning project.

September 24, 2009 – Dean of Agriculture Tour for PA Legislators and Agricultural Leaders – P. Heinemann, T. Baugher, J. Schupp, J. Liu, R. Dice, and A. Leslie presented impacts from Specialty Crop research initiative projects to 80 legislators and agricultural leaders.

October 21, 2009 – Tour for University of Maryland Advanced Technologies in Horticulture Class – T. Baugher, K. Ellis, J. Schupp, and Young Grower Alliance provided orchard demonstrations on innovations for specialty crops.

December 15, 2009 – Report for Funding Agency – T. Baugher and J. Remcheck met with the State Horticultural Association of Pennsylvania Extension Committee and provided an update on the SCRI grants received by Penn State.

December 16, 2009 – PA Pilot Orchard Lunch and Learn Session – J. Schupp, L. Hull, T. Baugher, and K. Ellis provided training on advanced IPM strategies for insect control, minimal pruning strategies to reduce labor requirements, and updates on comprehensive automation for specialty crops.

November 5, 2010 – Specialty Crop Tour for Young Growers – T. Baugher, J. Schupp, K. Ellis, and J. Remcheck facilitated a tour for 20 young growers to an innovative orchard in MD and a Delaware nursery utilizing new rootstocks for modern tree architectures.


November 10, 2010 – Spotlight on Assisted Harvest – T. Baugher, K. Ellis, G. Hoheisel, and E. Winzeler conducted a harvest platform demonstration for 20 members of the PA Ag Innovations Advisory Committee and the State Horticultural Association of PA.


February 2, 2010 – Advisory Panel Meeting in Conjunction with Mid-Atlantic Fruit and Vegetable Convention – CASC project leaders shared progress with Advisory Panel members and Pilot Orchard cooperators.

February 3, 2010 – Special Orchard Automation Session during Mid-Atlantic Fruit and Vegetable Convention – T. Baugher, K. Ellis, J. Schupp, P. Heinemann, and 4 growers who cooperated on field trials led a half-day session on orchard automation. There were 250 participants, and 156 participated in a survey to measure potential impacts – 58% indicated that as a result of educational programming they would likely plant new competitive orchard systems at higher tree densities, and 22% said they were already making changes; 53% responded that they would likely adopt new labor saving technologies, and 18% are already making changes; 55% said they were likely to adopt new IPM strategies/technologies for increasing precision and reducing environmental impacts, and 29% are already making changes.

presented an interactive session for 25 producers on considerations for successful orchard renewal and adoption of new technologies.


March 19, 2010 - Classroom in the Field at Mike Flinchbaugh’s and Justin Weaver’s Conservation Innovation Grant (CIG) planting for 16 Young Grower Alliance Members – J. Schupp and T. Baugher discussed apple and peach tree architecture systems for adaptability with automation.

May 13, 2010 – Classroom in the Field at Neil Starner’s Conservation Innovation Grant (CIG) planting for Pilot Orchard Cooperators – T. Baugher discussed two tree architecture systems for adaptability with automation.

June 21, 2010 - The ASABE annual meeting tour included a stop at Soergel Orchards in Pittsburgh, where the CASC team demonstrated the APM. There were about 60 visitors in the group, including 45 ASABE attendees, 4 CMU Summer Scholar interns, Soergel’s farm employees, and local middle-school students. In the first part of the demonstration Brad Hamner showed the vehicle following a few tree rows and turning from one row into another. He explained in detail each of the components of the autonomy system (sensors, computing, and actuation) and entertained a variety of technical questions from the audience. In the second part Matt Aasted showed the audience how to control the APM using the newly-developed grower-friendly APM user interface running on a field-ready handheld Panasonic tablet computer. He then let several attendees control the robot using the interface, including all the children present. People were able to use the interface with literally no training (especially the children!).

June 17, 2010 – Tour of Specialty Crop Innovation Projects at USDA-ARS Appalachian Fruit Research Station for 14 Young Grower Alliance members – S. Wolford demonstrated harvest assist technologies.

August 2, 2010 – USDA SCRI Director’s Workshop at the American Society for Horticultural Science Convention – S. Singh presented a progress report on the SCRI CASC Project.

August 26, 2010 – Fruit Technology Showcase at Penn State Fruit Research and Extension Center – B. Grocholsky, M. Aastad, J. Schupp, T. Baugher, K. Ellis, J. Remcheck, L. Hull, H. Ngugi, B. Lehman, G. Krawczyk, four graduate students, and six summer interns presented 2010 research results on Comprehensive Automation for Specialty Crops.

September 9, 2010 – Current and future strategies in nursery automation. J.S Owen presented update of caliper/counter to 11 industry leaders at J Frank Schmidt Nursery and Son, Co. and led to collaborative research for nursery inventory management with University of Arkansas and University of Florida.


September 20, 2010 – Specialty Crop Innovations Tour for University of California Extension Educators – J. Schupp and T. Baugher provided “train the trainer” programs for two tree fruit extension educators.


October 20, 2010 – Specialty Crop Innovations Open House and Harvest-Assist Demonstration at Penn State FREC. CASC project leaders had exhibits for 25 producers and legislators on each thematic area. Over 75 producers, agricultural leaders, and legislators (including aides to Senator Casey and Representative Platts) attended at demonstration on the CASC vacuum assisted harvest project.

December 19, 2010 – Penn State Extension In-depth workshop on “Plant Water Relations and Cropping Efficiency,” which featured CASC research on stress detection. Sixty producers attended the workshop, and in an exit survey, 82% of respondents indicated they learned something that has potential to make their businesses more profitable in the future, with new technologies on monitoring irrigation needs ranking highest. Respondents grew a combined total of 2326 acres of fruit.


February 22, 2011 - Ag Innovations – Progress and Future Directions Summit held in South Central Pennsylvania. Seventy producers and community leaders participated in a summit to develop strategies for preserving the Mid-Atlantic Fruit Belt through innovation.

March 10, 2011 - PA Pilot Orchard Lunch and Learn Session – J. Schupp, L. Hull, and T. Baugher provided training on advanced IPM strategies for insect control, minimal pruning strategies to reduce labor requirements, and updates on comprehensive automation for specialty crops (2011 trials planned with Allegheny APM and WeedSeeker).
March, 2011 – Tours of innovative PNW orchard systems and technologies for 300 International Fruit Tree Association Conference participants.

March 15, 2011 – Ag Tools Apple Grower Workshop held at Penn State FREC. Twelve producers and financial consultants attended an in-depth workshop on Ag Profit led by Clark Seavert and Jim Julian.


March 16, 2011 – Ag Finance Round Table held at Penn State FREC. Four ag lenders participated in a round table discussion to provide feedback on Ag Finance and Ag Lease.

March 17, 2011 – Specialty Crop Tour for Young Growers – T. Baugher, K. Ellis, and J. Remcheck facilitated a tour for 20 young growers to innovative orchard operations in Lancaster County, PA.

March 23, 2011 – Report for Stakeholder Group – J. Schupp and T. Baugher met with the State Horticultural Association of Pennsylvania Strategic Planning Committee and the Pennsylvania Apple Marketing Board director to update the group on progress with SCRI projects.

July 13, 2011 – Penn State Fruit Research and Extension Center Field Day – J. Schupp, L. Hull, H. Ngugi, T. Baugher, B. Hamner, and M. Bergerman presented field demonstrations relevant to the Mid-Atlantic fruit industry on Comprehensive Automation for Specialty Crops for 200 participants.

August 16, 2011 – Washington State University Sunrise Orchard Field Day – CASC team members presented field demonstrations on mechanical thinning, autonomous platform and automated trap.


March 23, 2011 – Report for Stakeholder Group – J. Schupp and T. Baugher met with the State Horticultural Association of Pennsylvania Strategic Planning Committee and the Pennsylvania Apple Marketing Board director to update the group on progress with SCRI projects.

December 6, 2011 – Tour of Specialty Crop Innovations in Two Pennsylvania Orchards for 20 Young Grower Alliance members.
December 15, 2011 - Report for Stakeholder Group – J. Schupp and T. Baugher met with the State Horticultural Association of Pennsylvania Extension Committee to update the group on progress with SCRI projects.

December 20, 2011 – Penn State Extension In-Depth Workshop on “Apple Cropload Management,” which featured new technologies for optimizing chemical thinning programs. Ninety-five producers attended the workshop.

February 11, 2012 – T. Baugher conducted Specialty Crop Innovations Tour for 25 Nebraska LEAD young agricultural leaders.

February 13-17, 2012 – K. Lewis led a producer tour to World AG Expo in Tulare, CA. Expo exhibits, field tours and facilitated round table discussions have resulted in a Technology roadmap for WSU CPAAS.

April 5, 2012 - Report on CASC activities at W1009 annual meeting by K. Lewis.

May 23, 2012–K. Lewis trained C & O nursery staff on the use of automated tree counter.

July 11, 2012 – T. Baugher conducted a Specialty Crop Innovations Tour for 85 Mid-Atlantic specialty crop producers.

September 28, 2012 – J. Schupp, T. Baugher and DBR Conveyor Concepts demonstrated the latest DBR harvester for Eastern orchard terrain and orchard systems for 35 Mid-Atlantic fruit producers.

October 2, 2012 – Washington State University Center for Precision Automated and Agricultural Systems conducted a technology expo and field day showcasing the CASC autonomous orchard vehicle “Cascade,” CASC harvest assist system, and mechanical thinners. The event was attended by 95 people.
Student Involvement
From left to right: Dr. Jim Schupp, student intern Evan Moore, graduate student Tom Kon, student intern Celine Kuntz, and technicians Katie Reichard and Edwin Winzeler conducting WeedSeeker research at PSU's Fruit Research and Extension Center.
Russell Rohrbaugh and Alex Leslie, Penn State ag engineering students, pruning trees in a commercial high density pilot orchard.
Reuben Disc with WeedSeeker.
Alex Leslie gives a talk on passive bin filler research at the CASC Open House in PA.
Reuben Dise and Tom Kon (on Reuben’s left) talk about the Weedseeker at CASC Open House in PA.
Brian Kliethermes and Gwendolyn Barr discuss the passive bin filler prototype with Prof. Sanjiv Singh and Prof. Bill Messner.
Jacob Koan, engineering intern from Michigan State, conducting mechanical thinning research.
Reuben Dise conducting string thinner positioning trial.
Reuben Dise recording data in string thinner positioning trial.
Penn State summer interns visited Mike Glenn (USDA-ARS) to learn about fruit tree physiology.
Matt Aasted and Reuben Dis testing sensors for automated positioning of string thinner.
Jackson Kowalski, intern at Oregon State’s North Willamette Research and Extension Center.

Brian Moore, intern at Oregon State’s North Willamette Research and Extension Center.
Mike Kapsimalis, intern at Oregon State’s North Willamette Research and Extension Center.

Sarah Sydow, intern at Oregon State’s North Willamette Research and Extension Center.
Robin Pritz, Kyle Tynan, and Dave Ferguson examine the APM after its seven-day trip across the country.
Matt Aasted (2nd from left), Robin Pritz (3rd from left), Jackie Libby (2nd from right) and Dave Ferguson (4th from right) join CASC researchers in field tests at Sunrise Orchard, WA.
Lily Li (on the APM), Lauren Von Dehsen (white jacket) and Matt Morrill (behind vehicle) during tests of the new APM user interface in Biglerville, PA.
Nicolas Liberum takes pictures of internal feeding worm injury for the development of computer algorithms to detect injury in orchards.

Jason Fissel checks the latest version of the electronic monitoring traps for capturing adult codling moth and oriental fruit moth in apples.
Matt Aasted instructs WSU’s Karen Lewis on the use of the new APM user interface.
Dani Peters working on the AgTools.org web site
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<tr>
<th>Name</th>
<th>Institution (*)</th>
<th>Area</th>
<th>Level of Study (**)</th>
<th>Thematic Area</th>
<th>Activities</th>
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<tr>
<td>Alex Leslie</td>
<td>Pennsylvania State University</td>
<td>Agricultural &amp; Biological Engineering</td>
<td>Undergraduate (S)</td>
<td>Augmented Harvesting, Outreach</td>
<td>Tested energy absorbing materials; built and tested mock-ups of passive bin fillers; assisted with efficiency trials in pilot orchards</td>
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<tr>
<td>Alex Reece</td>
<td>Carnegie Mellon University</td>
<td>Robotics</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed new user interfaces for the APM</td>
</tr>
<tr>
<td>Amelia Jarvinen</td>
<td>Pennsylvania State University/Oberlin College</td>
<td>Social Science</td>
<td>Undergraduate (S)</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Andrew Haun</td>
<td>Pennsylvania State University/Shippensburg University</td>
<td>Biology</td>
<td>Undergraduate (S)</td>
<td>Insect Monitoring</td>
<td>Assisted in checking traps on a daily/weekly basis; taking pictures of IFW injury in orchards</td>
</tr>
<tr>
<td>Anjali Patwardhan</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
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<tr>
<td>Art Flores</td>
<td>Washington State University/Columbia Basin Community College</td>
<td>Nursing</td>
<td>Undergraduate</td>
<td>Outreach</td>
<td>Assisted with outreach efforts and field trials of equipment at Washington State University</td>
</tr>
<tr>
<td>Asif Siddiqi</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
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<td>Bethany Ely</td>
<td>Pennsylvania State University</td>
<td>Communications</td>
<td>Undergraduate (S)</td>
<td>Insect Monitoring</td>
<td>Assisted in checking traps on a daily/weekly basis; checked for IFM injury in orchards</td>
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<tr>
<td>Brian Kliethermes</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Graduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
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<td>Brian Moore</td>
<td>Oregon State University/Clackamas Community College</td>
<td>Horticulture</td>
<td>Undergraduate</td>
<td>Caliper Measurement</td>
<td>Assisted in ground-truthing the on-the-go caliper device at Bailey and J. Frank Schmidt Nurseries</td>
</tr>
<tr>
<td>Caleb Tan</td>
<td>Purdue University</td>
<td>Electrical and Computer Engineering</td>
<td>Undergraduate</td>
<td>Insect Monitoring</td>
<td>Assisted in the assembly of digital trap prototypes</td>
</tr>
<tr>
<td>Caroline Song</td>
<td>Carnegie Mellon University</td>
<td>Information Systems</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for autonomous electric utility vehicles with a lift</td>
</tr>
<tr>
<td>Catherine Lara</td>
<td>Pennsylvania State University</td>
<td>Horticulture</td>
<td>Graduate</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Celine Kuntz</td>
<td>Pennsylvania State University/Millersville University</td>
<td>Economics</td>
<td>Undergraduate (S)</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Charlie Barber</td>
<td>Carnegie Mellon University</td>
<td>Industrial Design</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Claire Micklin</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Designed and field-tested a prototype grower-friendly interface for agricultural platforms</td>
</tr>
<tr>
<td>Cody Musselman</td>
<td>Pennsylvania State University/Kalamazoo University</td>
<td>Social Science</td>
<td>Undergraduate (S)</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Corinne Walters</td>
<td>Carnegie Mellon University</td>
<td>Computer Science</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for autonomous electric utility vehicles with a lift</td>
</tr>
<tr>
<td>Daniel Jolic</td>
<td>Pennsylvania State University</td>
<td>Engineering</td>
<td>Graduate</td>
<td>Outreach</td>
<td>Assisted with engineering modifications to autonomous orchard platform</td>
</tr>
<tr>
<td>David Ferguson</td>
<td>Carnegie Mellon University</td>
<td>Robotics</td>
<td>Graduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested algorithms for robust row turning</td>
</tr>
<tr>
<td>David Gossner</td>
<td>Oregon State University/Clackamas Community College</td>
<td>Horticulture</td>
<td>Undergraduate</td>
<td>Caliper Measurement</td>
<td>Assisted in ground-truthing the caliper device implemented on a shadetree digger and the counter device at J. Frank Schmidt Nursery</td>
</tr>
<tr>
<td>David Stonestrom</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Developed physics-based simulations of passive bin filing systems</td>
</tr>
<tr>
<td>Dong Hyun Choi</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Name</td>
<td>Institution (*), Institute (**)</td>
<td>Area</td>
<td>Level of Study (***)</td>
<td>Thematic Area</td>
<td>Activities</td>
</tr>
<tr>
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<tr>
<td>Esther Sollenberger</td>
<td>Pennsylvania State University/recent graduate from fruit grower family</td>
<td>Community Development</td>
<td>Looking at Graduate Programs</td>
<td>Outreach</td>
<td>Assisted with writing of outreach publications</td>
</tr>
<tr>
<td>Evan Moore</td>
<td>Pennsylvania State University/Grove City College</td>
<td>Social Science</td>
<td>Undergraduate (S)</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>German Holguin</td>
<td>Purdue University</td>
<td>Electrical and Computer Engineering</td>
<td>Graduate</td>
<td>Insect Monitoring</td>
<td>Designed and assembled digital trap prototypes</td>
</tr>
<tr>
<td>Gokhan Bayar</td>
<td>Carnegie Mellon University/Middle East Technical University, Turkey</td>
<td>Robotics</td>
<td>Graduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed enhanced dynamic models and control algorithms for autonomous electric utility vehicles</td>
</tr>
<tr>
<td>Guoqing Li</td>
<td>Purdue University</td>
<td>Electrical and Computer Engineering</td>
<td>Graduate</td>
<td>Plant Stress and Disease Detection</td>
<td>Developed algorithms for detecting internal feeding worm damaged apples</td>
</tr>
<tr>
<td>Gustavo Freitas</td>
<td>Carnegie Mellon University/Federal University of Rio de Janeiro, Brazil</td>
<td>Robotics</td>
<td>Graduate</td>
<td>Accurate Positioning</td>
<td>Developed enhanced laser odometry-based localization methods for autonomous electric utility vehicles</td>
</tr>
<tr>
<td>Gwendolyn Barr</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Graduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Helen Park</td>
<td>Carnegie Mellon University</td>
<td>Writing</td>
<td>Graduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Jackson Kowalski</td>
<td>Oregon State University/University of Puget Sound</td>
<td>Biological Systems</td>
<td>Undergraduate</td>
<td>Caliper Measurement</td>
<td>Assisted in ground-truthing the on-the-go caliper device at Bailey and J. Frank Schmidt Nurseries</td>
</tr>
<tr>
<td>Jacob Koan</td>
<td>Pennsylvania State University/Michigan State University</td>
<td>Agricultural Engineering</td>
<td>Undergraduate (S)</td>
<td>Augmented Harvesting, Outreach</td>
<td>Tested energy absorbing materials; built and tested mock-ups of passive bin fillers; assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Jacqueline Libby</td>
<td>Carnegie Mellon University</td>
<td>Robotics</td>
<td>Graduate</td>
<td>Accurate Positioning</td>
<td>Developed and field-tested algorithms for vehicle localization</td>
</tr>
<tr>
<td>James Kim</td>
<td>Purdue University</td>
<td>Electrical and Computer Engineering</td>
<td>Post-doctoral</td>
<td>Plant Stress and Disease Detection</td>
<td>Carried out performance evaluation of NDVI sensors; Designed multi-sensor system for stress and fire blight detection</td>
</tr>
<tr>
<td>Jason Yore</td>
<td>Carnegie Mellon University</td>
<td>Industrial Design</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for autonomous electric utility vehicles with a lift</td>
</tr>
<tr>
<td>Jen Nelson</td>
<td>Oregon State University</td>
<td>Horticulture</td>
<td>Undergraduate Intern (S)</td>
<td>Caliper Measurement</td>
<td>Assisted in the field deployment of caliper and counter and analysis of results</td>
</tr>
<tr>
<td>Jennifer Rouzer</td>
<td>Pennsylvania State University/McDaniel College</td>
<td>Biology</td>
<td>Undergraduate (S)</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Ji Zhang</td>
<td>Carnegie Mellon University</td>
<td>Robotics</td>
<td>Graduate</td>
<td>Accurate Positioning</td>
<td>Low-cost systems for orchard vehicle localization</td>
</tr>
<tr>
<td>John Michael Flowers</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Designed and field-tested a prototype grower-friendly interface for agricultural platforms</td>
</tr>
<tr>
<td>John Ni</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Julie Bai</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Designed and field-tested a prototype grower-friendly interface for agricultural platforms</td>
</tr>
<tr>
<td>Juliet Hulse</td>
<td>Pennsylvania State University</td>
<td>Biology</td>
<td>Undergraduate (S)</td>
<td>Insect Monitoring</td>
<td>Assisted in checking traps on a daily/weekly basis; checked for IFM injury in orchards</td>
</tr>
<tr>
<td>Julius Tarn</td>
<td>Carnegie Mellon University</td>
<td>Industrial Design</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for autonomous electric utility vehicles with a lift</td>
</tr>
</tbody>
</table>

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<table>
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<th>Level of Study (**)</th>
<th>Thematic Area</th>
<th>Activities</th>
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</thead>
<tbody>
<tr>
<td>Jung Hwan Park</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Kan Tao</td>
<td>Carnegie Mellon University</td>
<td>Chemical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Kara Woodward</td>
<td>Oregon State University/Portland</td>
<td>Horticulture</td>
<td>Undergraduate</td>
<td>Caliper Measurement</td>
<td>Assisted in ground-truthing the counter device at J. Frank Schmidt Nursery</td>
</tr>
<tr>
<td>Katie Reichard</td>
<td>Pennsylvania State University</td>
<td>Horticulture</td>
<td>Graduate (S)</td>
<td>Outreach</td>
<td>Assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Kelly Lau-Kee</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Kevin Chung</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Krupa Mehta</td>
<td>Carnegie Mellon University</td>
<td>Engineering Technology Innovation Management</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Kuan-Po Chen</td>
<td>Purdue University</td>
<td>Electrical and Computer Engineering</td>
<td>Undergraduate</td>
<td>Insect Monitoring</td>
<td>Assisted with the development of a solar harvesting system</td>
</tr>
<tr>
<td>Laura West</td>
<td>Carnegie Mellon University</td>
<td>Industrial Design</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Lauren Von Dehsen</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for the APM</td>
</tr>
<tr>
<td>Le Wei</td>
<td>Carnegie Mellon University</td>
<td>Computer Science</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for autonomous electric utility vehicles with a lift</td>
</tr>
<tr>
<td>Lily Li</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for the APM</td>
</tr>
<tr>
<td>Luke Kambic</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Marcel de Sena Dall'Agnol</td>
<td>Carnegie Mellon University</td>
<td>Robotics</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility, Caliper Measurement</td>
<td>Assisted with creation of an off-line GPS data correction tool and with field tests of an autonomous orchard vehicle</td>
</tr>
<tr>
<td>Mark Slabinski</td>
<td>Carnegie Mellon University</td>
<td>Professional Writing</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Matt Aasted</td>
<td>Carnegie Mellon University</td>
<td>Robotics</td>
<td>Graduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a system to automate thinning with the Darwin machine</td>
</tr>
<tr>
<td>Matt Morrill</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Developed and field-tested a grower-friendly interface for the APM</td>
</tr>
<tr>
<td>Matthew Hartwig</td>
<td>Pennsylvania State University</td>
<td>Biology</td>
<td>Undergraduate (S)</td>
<td>Insect Monitoring</td>
<td>Assisted in checking traps on a daily/weekly basis; checked for IFM injury in orchards</td>
</tr>
<tr>
<td>Mattie Kuntz</td>
<td>Pennsylvania State University</td>
<td>Biology</td>
<td>Undergraduate (S)</td>
<td>Plant Stress and Disease Detection</td>
<td>Assisted with laboratory, greenhouse and field studies on tree stress and fire blight detection</td>
</tr>
<tr>
<td>Mike Kapsimallis</td>
<td>Oregon State University</td>
<td>Horticulture</td>
<td>Graduate student intern</td>
<td>Caliper Measurement</td>
<td>Assisted in the field deployment of caliper and counter and analysis of results</td>
</tr>
<tr>
<td>Mukul Bhatt</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Natasha Tan</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Designed and field-tested a prototype grower-friendly interface for agricultural platforms</td>
</tr>
</tbody>
</table>
| Nicolas Liebrum | Pennsylvania State University    | Bio-engineering                                 | Undergraduate (S)  | Insect Monitoring                   | Assisted in checking traps on a daily/weekly basis; taking pictures of IFW injury in orchards                                                                                                              

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<th>Activities</th>
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</thead>
<tbody>
<tr>
<td>Patricia Loring</td>
<td>Carnegie Mellon University</td>
<td>Professional Writing</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Paul Kimball</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Randy Lee</td>
<td>Carnegie Mellon University</td>
<td>Biomedical Engineering</td>
<td>Graduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Reuben Dise</td>
<td>Pennsylvania State University</td>
<td>Agricultural &amp; Biological Engineering</td>
<td>Graduate</td>
<td>Augmented Harvest, Outreach</td>
<td>Researched and helped modify orchard harvest platform for autonomous control; assisted with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Robin Pritz</td>
<td>Carnegie Mellon University/Pennsylvania State University</td>
<td>Robotics</td>
<td>Undergraduate (S)</td>
<td>Augmented Harvesting, Reconfigurable Mobility</td>
<td>Designed and developed novel bin-filling systems, assisted with APM field testing</td>
</tr>
<tr>
<td>Russell Rohrbaugh</td>
<td>Pennsylvania State University</td>
<td>Agricultural Systems Management</td>
<td>Undergraduate</td>
<td>Augmented Harvesting, Outreach</td>
<td>Assisted with efficiency trials in pilot orchards and harvest platform</td>
</tr>
<tr>
<td>Ryan Hilton</td>
<td>Pennsylvania State University</td>
<td>Alternative Energy/Engineering</td>
<td>Undergraduate (S)</td>
<td>Augmented Harvesting, Outreach</td>
<td>Assisted with energy efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Sangwon Lee</td>
<td>Carnegie Mellon University/James Madison University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Sarah Sydow</td>
<td>Oregon State University</td>
<td>Horticulture</td>
<td>Graduate student intern</td>
<td>Caliper Measurement</td>
<td>Assisted in the field deployment of caliper and counter and analysis of results</td>
</tr>
<tr>
<td>Seoyeon Yang</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and developed novel bin-filling systems</td>
</tr>
<tr>
<td>Sladjana Prozo</td>
<td>Pennsylvania State University</td>
<td>Socio-Economics</td>
<td>Graduate</td>
<td>Augmented Harvesting</td>
<td>Designed apple unloading mechanism to improve worker safety and maintain efficiency and current levels of apple quality</td>
</tr>
<tr>
<td>Sunny Chan</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed and field-tested a prototype grower-friendly interface for agricultural platforms</td>
</tr>
<tr>
<td>Tiffany Ng</td>
<td>Carnegie Mellon University</td>
<td>Human-Computer Interaction</td>
<td>Undergraduate</td>
<td>Reconfigurable Mobility</td>
<td>Designed and field-tested a prototype grower-friendly interface for agricultural platforms</td>
</tr>
<tr>
<td>Tom Kon</td>
<td>Pennsylvania State University</td>
<td>Horticulture/Pomology</td>
<td>Graduate</td>
<td>Augmented Harvesting</td>
<td>Designed with efficiency trials in pilot orchards</td>
</tr>
<tr>
<td>Tristram Hogben</td>
<td>Carnegie Mellon University</td>
<td>Mechanical Engineering</td>
<td>Undergraduate</td>
<td>Augmented Harvesting</td>
<td>Designed novel mechanisms for handling apples during harvest</td>
</tr>
<tr>
<td>Tyler Hoskins</td>
<td>Oregon State University/Clackamas Community College</td>
<td>Horticulture</td>
<td>Undergraduate Intern</td>
<td>Caliper Measurement</td>
<td>Assisted in the field deployment of caliper and counter and analysis of results</td>
</tr>
<tr>
<td>Wei Jian Chan</td>
<td>Purdue University</td>
<td>Electrical and Computer Engineering</td>
<td>Undergraduate</td>
<td>Insect Monitoring</td>
<td>Assisted with the development of a solar harvesting system</td>
</tr>
</tbody>
</table>

(*) When two institutions are listed, the first is where the student is interning for CASC work and the second is his/her home school.

(**) (S) indicates summer intern.
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