2015 KEYNOTE ADDRESS
Horticultural Applications of Unmanned Aerial Systems

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Good morning. I would like to talk to you about unmanned aerial vehicles (UAVs). And, I hope at the end of my talk you get an idea about what we can do with UAVs, why it is so important and how you can use it in your research.

No weeks go by without you hearing something in the news and media about the application of UAVs. Because of this interest, I want to show you that it is a very useful technology for specialty crops, especially horticultural crops.

UAVs, also called drones, are like certain other advanced technologies being used by agriculturists, in that many of them have been initially used by the military or have military applications. Initially, military uses for UAVs focused on three missions: dull, dirty, and dangerous. Dull like ground flight, surveying, long flights (30 hours); dirty like collecting radiation samples after a nuclear blasts (the military used drones for this purpose as far back as 1948). Drones have also been used for dangerous missions, such as reconnaissance flying in hostile territory.

Agricultural uses for UAVs can also include dull, dirty, and dangerous. Scouting for diseases is an example of dull, just flying through rows and rows of trees looking for symptoms. The relatively sudden recent interest in UAVs can be attributed to two interesting things. One is that the Federal Aviation Administration (FAA) a couple of years back opened United States air space for commercial use of UAVs. The FAA had planned to publish rules for the integration of commercial unmanned aerial systems into U.S. national air space by the year 2015, but the agency did not meet this deadline. The rules are not yet in place, and it seems like it will probably be two more years until we actually see such rules. But there is an Association of Unmanned Systems International (AUVSI); it's a very large group of people that are working on unmanned aerial systems.

The FAA did a study to look at the economic impact of UAV systems for different states. For example, you see the first two years of integration of UAVs, we're looking at a $600 million dollar impact for the State of Florida, creating about 3,251 jobs and the impact of 10 years would be $3.8 billion dollars with 4,000 jobs (Fig. 1). So how did the FAA come up with this number? Well they looked at different applications and they also estimated how many UAVs could be sold. This FAA study indicated that agriculture is the biggest market for UAVs. And, the FAA projected that 30 to 40 thousand UAVs per year would be purchased, mostly for agricultural applications.

So, suddenly agriculture became a very important potential market because its economic impact is biggest of all of the potential markets. That drew the attention of a lot of investors, a lot of companies and defense contractors. All of a sudden they started talking about, "What can we do in agriculture?" First they had to figure out what could do UAVs in agriculture, and then determine applications for UAVs.

Table 1: Total Economic Impact of UAS Integration in the United States

State	2015 - 2017			2015-2025		
	Economic Impact $(M)	Taxes ($M)	Jobs Created	Economic Impact ($M)	Taxes ($M)	Jobs Created
Alabama	$294	$2.43	1,510	$1,765	$14.60	2,231
Alaska	$19	$0.00	95	$112	$0.00	141
Arizona	$561	$2.59	2,883	$3,371	$15.55	4,260
Arkansas	$80	$0.94	411	$481	$5.63	608
California	$2,390	$13.64	12,292	$14,372	$82.03	18,161
Colorado	$232	$1.79	1,191	$1,392	$10.76	1,760
Connecticut	$538	$4.32	2,764	$3,232	$25.97	4,084
Delaware	$17	$0.16	88	$103	$0.97	131
Florida	$632	$0.00	3,251	$3,801	$0.00	4,803
Georgia	$379	$3.72	1,949	$2,279	$22.34	2,880
Hawaii	$32	$0.39	166	$194	$2.35	245
Idaho	$29	$0.36	149	$174	$2.16	220
Illinois	$204	$1.71	1,049	$1,226	$10.30	1,549
Indiana	$208	$1.18	1,067	$1,248	$7.12	1,577
Iowa	$159	$0.92	817	$956	$5.53	1,208
Kansas	$489	$4.84	2,515	$2,941	$29.13	3,716
Kentucky	$89	$0.90	459	$537	$5.41	678
Louisiana	$213	$1.44	1,097	$1,282	$8.67	1,620
Maine	$107	$1.26	548	$641	$7.56	810
Maryland	$335	$2.64	1,725	$2,017	$15.85	2,549
Massachusetts	$386	$3.36	1,985	$2,321	$20.22	2,933
Michigan	$188	$1.37	965	$1,128	$8.26	1,426
Minnesota	$142	$1.68	730	$853	$10.08	1,078
Mississippi	$162	$1.10	832	$973	$6.60	1,230

Fig. 1. Total Economic impact of UAS integration in the United States. Source: <http://www.aucsu.org/aubsi/resources/old/economicreport/>.

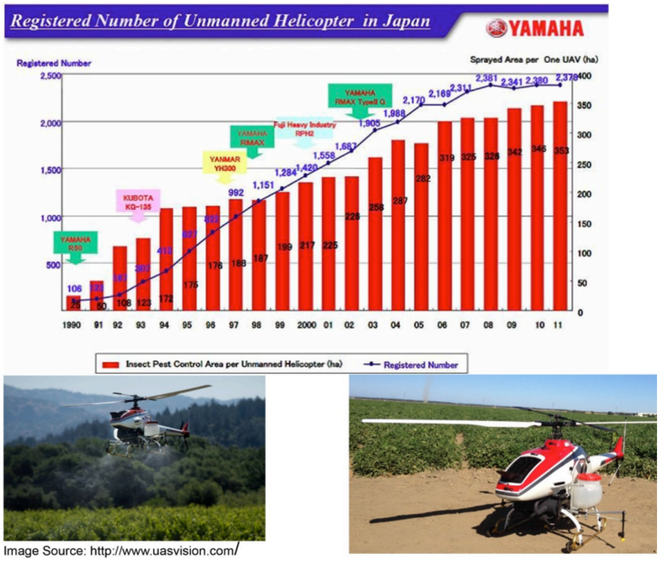

Fig. 2. Unmanned helicopter usage in Japan.

How did the FAA study come up with this 30 to 40 thousand UAVs purchased per year; how did they predict they would be able to sell so many of them? Well, they looked at other countries; it turns out that Japan is one of the countries that had been using unmanned aircraft for a long time, special helicopters called RMAX, used in spraying chemicals in paddy fields (Fig. 2). Growers in Japan started using these in the 1990s and the FAA study looked how many were sold in Japan and what the growth of this technology was. It turns out that the majority of the fields in Japan right now are being sprayed by RMAX, so it is a very reliable platform. Based on the growth of UAV use in Japan, the FAA study predicted that the same thing may happen in the United States.

Unmanned aerial vehicles can be divided into two general classes: fixed wing and rotary wing. Rotary wing UAVs can be single wing (like the RMAX) or the can be multi-rotary wings (Fig. 3). They can be small or large; for agricultural uses we are looking at the small ones because the way the rules and regulations are written now, they favor the smaller UAV, one that weighs less than 55 lbs.

In general, we can put UAVs into two categories. There are hobby grades which are lower cost, mostly anything you can buy for less than $10,000, and then there are the professional grades, priced at $50,000 and up. The hobby grades are really not designed for continuous use and they have not been heavily tested. They may be prone to signal interference; they may lose GPS signals quickly. When I say you get what you pay for, I should also say that I am one of those people who have been using the hobby grade UAVs extensively over the past 5 to 6 years and I've noticed significant improvement in the capability of these systems. The technology development is similar to the technology shifts that we see in computers. You see every day that there is better technology at a lower cost. It's the same thing I have observed happening in UAVs.

Now let's take a look at fixed wing UAVs (Fig. 4). Fixed wing UAVs are hand launched and battery operated. We've used this type of UAV to take aerial photos of groves. It's all free autonomous, it is preplanned as you can see on the monitor and the operator is just monitoring it. As you can see, it is flying all on its own. But there can be an operator to take over if something happens. All of this technology has a built in system, so that in case it looses communication, the UAV will come back to its home position. There are lots of safety and security measures built into this system. One issue with the fixed wing systems is that a good runway is needed to take off and land. The advantage of such systems is that they are able to stay airborne for longer time periods, and therefore, they can cover more ground.

The alternative to the fixed wing system is the rotary wing system (Fig. 3, Fig. 5). These are good for applications in agriculture, as they can take off and land from a very limited space, a decided advantage. The disadvantage is that rotary wing systems can only fly 20 minutes maximum, so you are limited to the area that can be covered. Both systems are navigated by global positioning system (GPS) technology.

For each of these systems, fixed wing and rotary wing, there are three operating components. There is a mission planning system; the operator downloads the area desired to fly in and creates a boundary. The software creates the resolution desired, and creates the flight path. Very little knowledge of computers is needed to operate this. It is very simple to operate.

Many people believe that the UAVs' most important application would be in precision agriculture and I'm just going to talk a little bit about what has been done in precision agriculture and why UAVs can fill gaps that exist now.

Fig. 3. Rotary wing UAVs.

Fig. 4. Fixed wing UAVs.

Fig. 5. Rotary wing unmanned aerial vehicle.

So let's review a quick history of precision ag. We used to have smaller fields, more farmers, and because individual farms were small, the growers were able to actually monitor their fields on their own. They were able to just walk and check and decide if they needed to add fertilizer or if they needed to remove the weeds. Then as the farms became larger, it was not easy for growers to go out and visually check the field as often. As a result, back in the 1990s we developed precision ag technology. In fact it started with application of low cost computers and GPS. So the idea was to find the crop response and to manage the fields in such a way that it maximized yield. We can look at low productive areas and high productive areas and treat them differently as crop responses would be different in different locations. And to do that we need to define the crop response to the different inputs. So this required collecting a lot of data. Precision ag started back in the 1990s, and had a yield monitoring component built into them and they were able to actually quantify yield, so they were able to create yield maps (Fig. 6). And yield maps were the first steps in quantifying yield validity which helped us to start implementing precision ag.

This was very exciting for the growers; they saw that they could accurately predict yield by using these yield maps. The difficulty they experienced was the uncertainty about why the yield would be low in one area and why it was higher in other areas. And it turns out that answering that question was not so easy, more data was needed. So we had to look at yield as a function of the other inputs. There are many factors that could influence yield and to answer the question and to understand the cause of the variability, you also need to understand all other input factors. Disease affects efficiency, as do soil variability and soil fertility, and all the other factors (Fig. 7) are involved in it. To do that then, there is the need to build more sensors, sensors that can measure soil variability, sensors that can measure pests and disease and so on. And then they start to put those into different platforms. So we have to build different sensors to be used for different platforms.

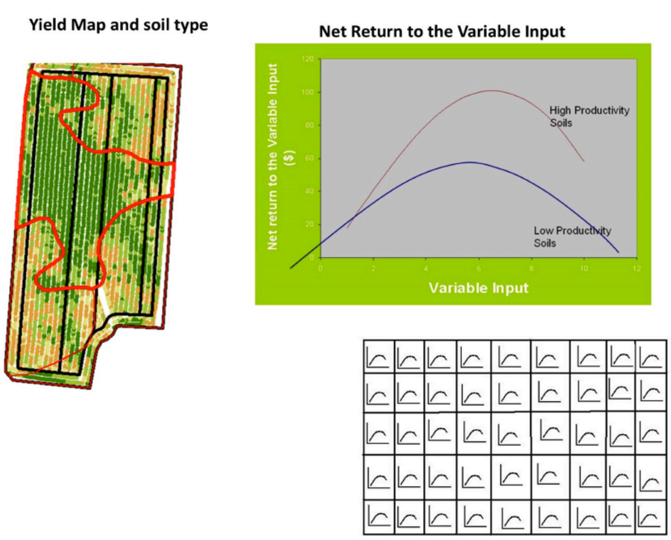

Fig. 6. Yield mapping .

Well, if the grower tried to take one hand-held device and walk to every tree and collect data that was time consuming and not very efficient. The alternative was to install a sensor on a tractor and run the tractor through the field, or to use aerial based platforms, such as UAVs, that could be flown over the growing areas to gather the information.

And that is why remote sensing from day one was considered a major component of precision ag. So again, remote sensing is nothing new. We have had remote sensing for the last 20 years. We had satellite imagery, we had piloted airplanes. The challenge was that, although this technology was available, if you look at the literature, you will see that they are very rarely used at the grower level. So not many growers were using this technology, mainly because of cost, as well as timeliness. Growers often needed to collect data in a very short window of time and it was very hard to get that information with a piloted airplane. And, we really need a high resolution. With many row crops we needed to look at things in a very, very high resolution, especially, for example, for disease detections. In many cases, individual leaves had to be examined, and that means you need to have accuracy, so much accuracy, which you couldn't get with the satellite or with the piloted airplane.

So UAVs started to be interesting for horticultural crops because, unlike other technologies used by agronomic crops, UAV technology, in fact, started with high value crops because it has a specific application with high value crops. I'm going to start to go through some of those applications.

So what are those applications? We can divide those applications into passive applications and active applications. Passive applications include detecting stress, monitoring crop growth, yield estimations, estimating herbicide efficiency, water use and chemical applications.

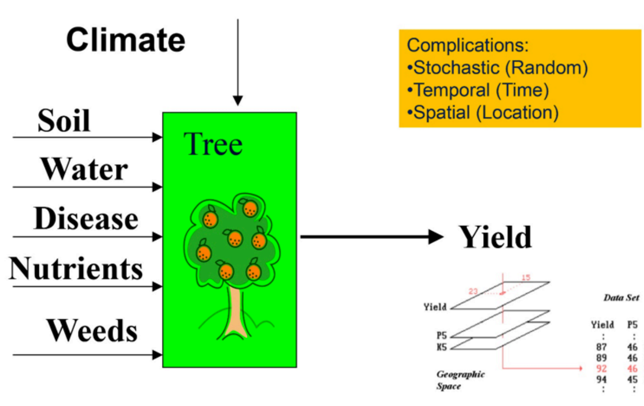

Fig. 7. Data variables.

Passive applications include what I call the view from above. You can see which areas have large trees which areas have smaller trees and as you go higher you can even compare this row with the next row, and so on. And nothing can replace the knowledge of the grower and the scientist then when they can look at the field from the top. So you are able to say, “Oh what going on in those two rows” or “What’s that fire going on over there?” You couldn’t see these things at ground level.

Another thing is that if you found a section that interests you, then you can send your UAV to those coordinates and then in fact look at those trees very, very closely. You can also look between the rows and you can decide what’s needed. And you can do all these things while sitting indoors, and monitor this without having to walk into the hot area to get that information, an important advantage.

Now we have a view from Malaysia, and it is clear that in this field there is one area where the trees are not growing as well as the others. So this is just an interesting observation that some part of this field is not well. And you can look at another part of the field and see that some of the leaves are yellow. So as I said this is just a quick way of just quantifying what is happening in the field in just a very short flight. As I said if you just go and walk this field it would be very hard to see this type of general pattern from the ground level.

So, the UAVs can collect images, and the software can allow these images to be stitched together. We can stitch them to create a 3D from a 2D image and this is all done with software so you can create a visual map of your field. This image shown was all created from a 2D image (Fig. 8).

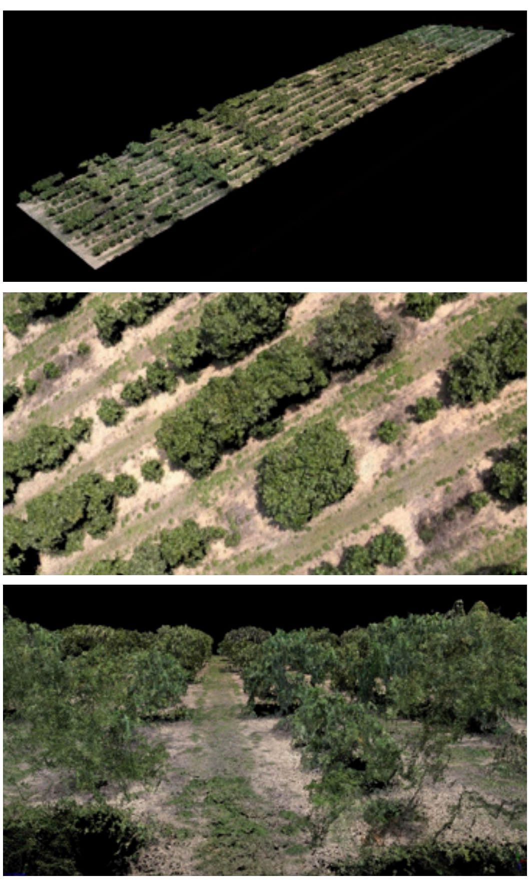

Fig. 8. High resolution images: (top) 3D generated image; (middle) overhead view; and (bottom) ground view.

Another interesting application is disease and stress detection and this is how I first got started working with UAVs. If you remember back in 2006 and 2007, we had HLB disease and back then the recommendation for management of this disease was to scout the field and find the infected trees and remove them. And to do the scouting we had this crew of people that would walk through rows and rows of trees and they’re trying to observe disease symptoms. And one of the things they found out was that they could see much better if they used a raised platform, similar to how it is done in Brazil. There were two difficulties: first of all these scouts at best had 60% accuracy in detecting so 40% of the time they missed the symptoms. The second problem was that this raised platform was not OSHA approved, we couldn’t legally use it in this country. So, we started thinking about how we can do this without using a raised platform. We learned about UAV and how some hobby grade UAVs could be used and that’s how we bought it and put it together back then. The way this system worked is we looked at the spectral reflectance of the leaves and most of the time the disease and stress causes some variation in the spectral characteristics of the leaves of the plants. By finding out where are the locations of those bands and identifying those bands we were able to try to detect that particular disease.

This is an example of the work we did with Dr. Jonathan Crain and Dr. Randy Ploetz on detecting laurel wilt. We were looking at the spectral difference in laurel wilt and we observed that spectral started to change as the disease progressed; using this characteristic we were able to actually detect the disease at a very early stage.

This is an example of the camera used, basically a six band camera and you determine the filters based on what you are looking for and you put it on the camera and you fly (Fig. 9). This is still an expensive kind of camera but what you can see is that the market has a lot of different cameras that can be modified to take the photos. These are basic cameras that have been modified. Using this kind of sensor you can get some general idea of the stress, it doesn’t tell you what kind of stress you have with it but tells you that there is some stress going on. The good thing about it is it is fairly cheap and there are hyper-spectral cameras that collect spectral data for the whole range. These can be fairly expensive; they can cost more than your whole UAV.

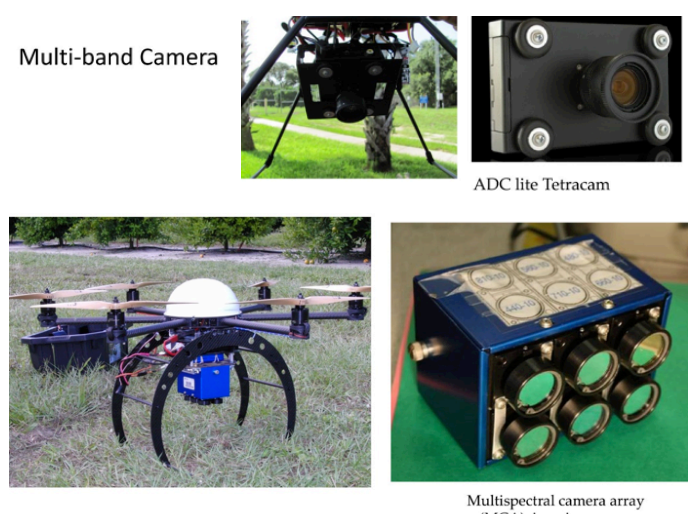

Fig. 9. Multi-band camera.

This is a photo of a golf course and you can see that the first area can be detected but it's very hard to tell what caused that distress, that's one step and it kind of gives you some information about the areas that have issues and you can send somebody to look at area and what is the cause of it (Fig. 10). We also looked at detecting the greening and doubled up the numbers and of course this was at the symptomatic stage, it's not possible to detect asymptomatic stage with the spectral band we are using. So we compared the manned airplane with the unmanned and you can see that the big difference is the improved resolution. With the manned, you get about 20 inches per pixel and, with the unmanned 2 inches per pixel. So you can see it's a much higher resolution (Fig. 11). But as it turns out this higher resolution helped increase the accuracy of the detection by about 10% so we noticed that when we have higher resolution image we can detect with the same algorithm we can improve our detection accuracy.

Another emerging area is thermal imaging; in fact UAV brought this concept more in the forefront using thermal imaging for different applications. The good thing about thermal imaging is that it can complement the images you get with the visible spectrum photographs. This is an example of 100 potted plants; 12 of them are water stressed and there is no way you can visually detect which ones are water stressed. But if you look at the thermal image you can clearly see those 12 plants that are slightly water stressed (Fig. 12). So this is one of the things I'm talking about with UAV and its application, it's not limited to human, it goes beyond a human's capability to do things. In Europe, they use the UAV to detect weeds based on their spectral imagery. They go one step further and actually create application maps so they can send their ground crew sprayers to those locations so they can turn their sprayers on and off based the information and based on their application map.

UAVs can be a very useful tool for researchers. This photo is a field trial in Idaho (Fig. 13), evaluating a combination of fertility and irrigation effects. These four trees were sprayed with high nitrogen and the other four trees with low nitrogen and there were all these combinations they were using. In fact, photo-typing is a big of application of UAVs. High true good photo-typing is growing that there are universities that are hiring post docs that are doing this, high resolution photo-typing using UAV.

Inventory management this is another important application for UAV. We received a grant from Oregon Department of Agri-

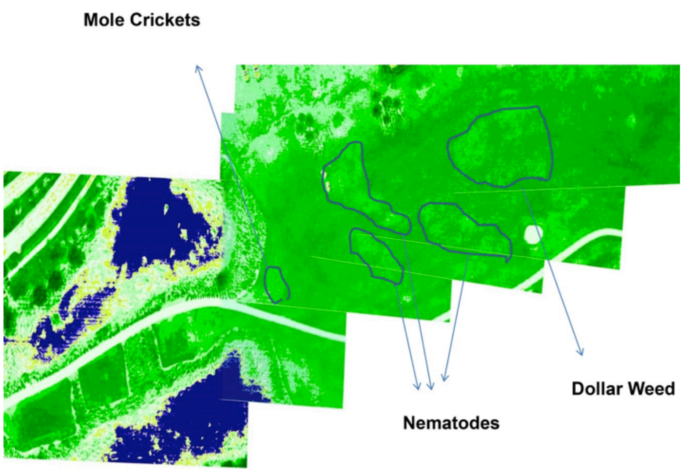

Fig. 10. Arial view of golf course showing distress.

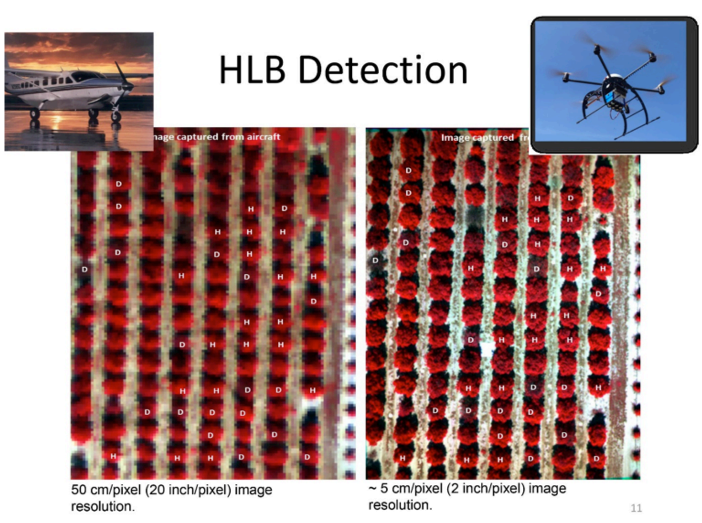

Fig. 11 Image resolution of photos taken from manned (left) and unmanned (right) aircraft.

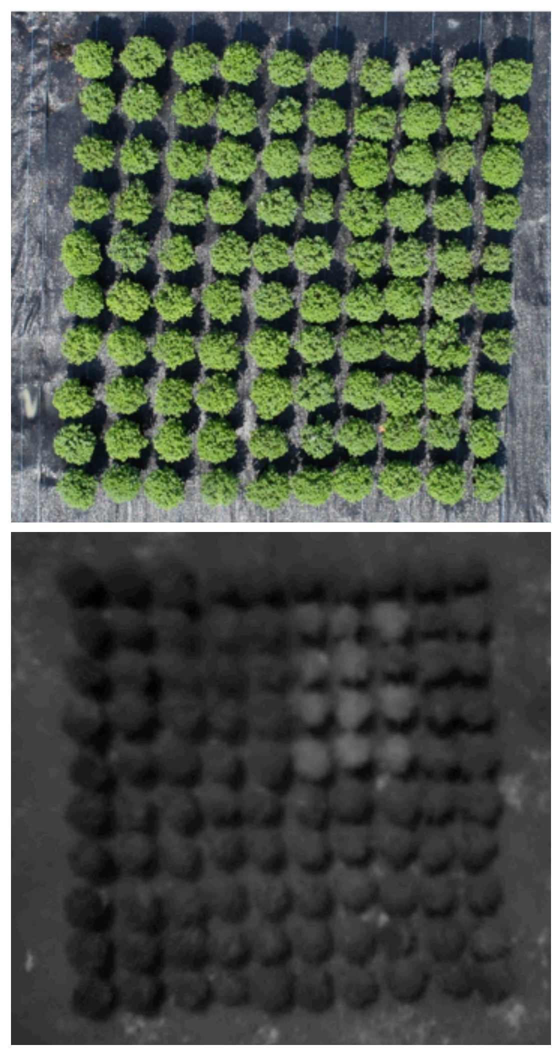

Fig. 12. An example of thermal imaging in use to detect water stress. Top: normal view. Bottom: thermal imaging reveals water stress.

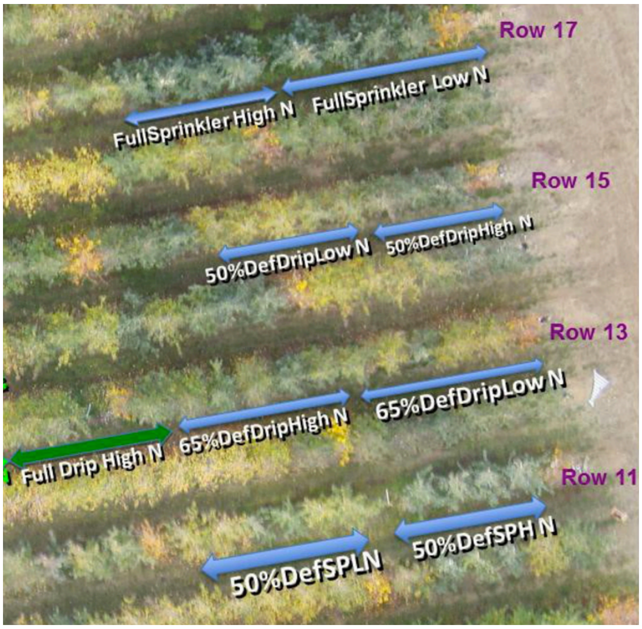

Fig. 13. High resolution photo-typing in a potato field.

culture for field grown nurseries. This photo is a Christmas tree farm (Fig. 14). What they wanted to know is how many Christmas trees are here. They didn't know, it's funny they plant these things and they have no clue how many they have. They need to know for inventory application, to know how many trees they have for sale; they want to know quality, what good quality, what's low quality.

In an open field nursery, it's a very good application and it's a very good application for a smaller field. Oregon has large open field nurseries and the biggest is 1,000 acres. They have all kinds of pots, and they have no idea how many they have, and they want to know and they have 700 different varieties and it's very hard for them to evaluate them. This is a photo of the area (Fig. 15) and I looked at this particular block, marked in red, and this is a partially harvested block, which means that some of the plants had been sold, and some remain. The sold plants were taken randomly, so this is what it looks like now and they want

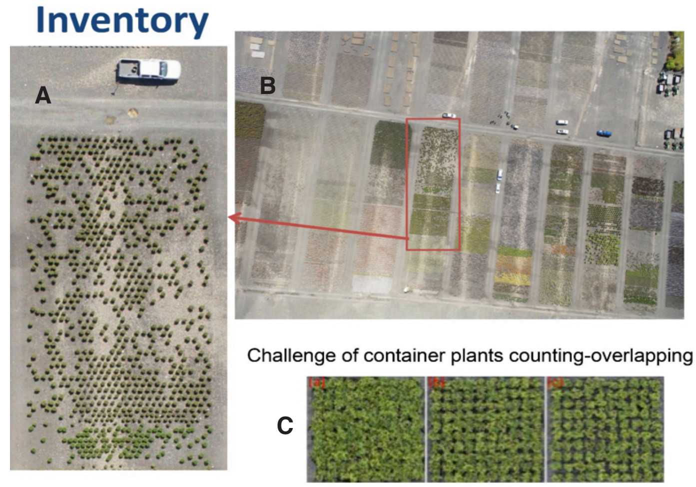

Fig. 15. This close-up view (**A**) in an open field nursery (**B**) details the random nature of the harvest. (**C**) Aerial view of overlapping canopies—a challenge to inventory control.

to know how many they have. If the grower sends someone out to count it's not possible to get an accurate number. The grower could send 10 different people out and they would have 10 different numbers, as people tend to lose count. But if you take an image of the area and print this picture and have someone use tic marks, the number of remaining plants can be counted fairly fast and accurately. Or you can develop an algorithm to count these. The challenge is the situation we have in the lower part of the picture when you have a plant with overlapping canopies. So if I ask you how many pots you have in this, there is no way you can count it because of the overlap. Even a human cannot count that because you have the overlapping canopies. But in fact you can buy the software that can do that.

Now this is Cherry Lake Nursery in Groveland, FL, (Fig. 16) and they have all these groves and they want to know how many they have so we use our algorithm and give them a count. It turns out our count had about a 5% error but the reality is that I don't trust their count because I based it on the number they gave me and I tried to do it myself and it's not easy. You start counting and after a while you forget how many you have. We

Fig. 14. Using UAV imaging for Christmas tree inventory management.

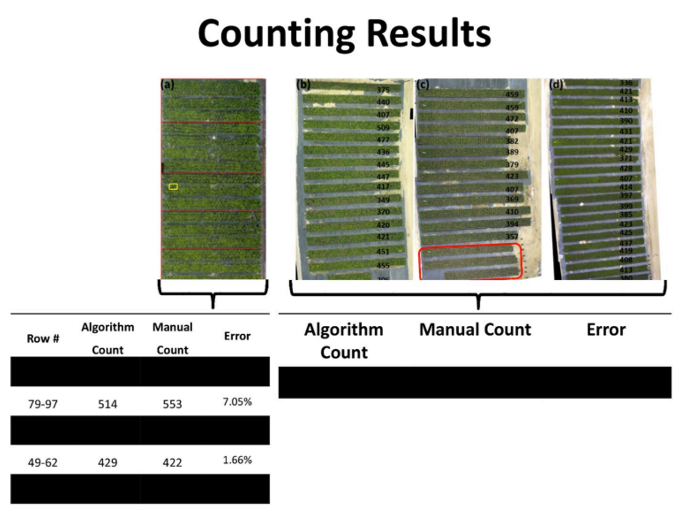

Fig. 16. Using a counting algorithm and UAV imagery for inventory control.

might be better than 5%, we don't know but it's a very useful thing for them because inventory management is a big part of their expenses. And you can also measure the size of the canopies and figure out the size distribution and then you can use that for other applications such as yield monitoring.

Another application is insect mapping. So, can you use UAVs for insect counts? We took a high resolution photo of sticky traps. By zooming in and we are able to get a picture of the individual sticky trap. There are people that look at pathogens and they can look at the pathogens in the air and they can actually look at the different pathogens at different elevations. So this is one application and then you can also look at for example mapping the pathogen and here we were looking at the psyllid. Well it turns out the psyllid is very small, it's only about 3 mm long, so even with a high resolution camera you can see something but you can't actually see if it is the psyllid or not. Now that is with the camera we used, but maybe with a higher end camera and detect whether or not it is a psyllid. But what we did was we wrote an algorithm that says anything less than 3 mm and anything above take the picture and crop it, well it could be some psyllid or it could be just trash. But we tried it an actually created a map.

This is an organic field that we used because we could find lots of psyllids (Fig. 17). And, this kind of map tells you the distribution of the psyllid; in fact, one thing you can see is the border areas have a higher psyllid concentrations (that's what entomologist tell us all the time). We not only can quantify, but we can quantify over time, so you can look at the progress of the infestation. Or you can monitor the effectiveness of psyllid control measures. You may not need to spray a whole field; you may decide to spray the boundary more so than the center.

Yield estimation and yield monitoring is another example of UAV technology. So how can we estimate yield? We helped on a project in Chile; what they had previously done is to get yield estimation by randomly selecting fields and take a count of fruit sets and estimating based on that. But this time, using UAVs, they took an aerial image of the field. And then decided to move up the quality with a small sampling, you decided on which area has high productivity and the area that's lower productivity and then you take your sampling based on that variability. Based on their sampling point, it's not random anymore, it's more based on zones, it's random within the zones but they have this software that they use in their estimation. So now they go to those particular points and they do the counting of the fruit sets and they do their fruit yield estimation on that. They create their report from that and are very accurate within 5% to 10%.

Another of my projects is working with a professor at the University of Pennsylvania to develop an algorithm to do fruit count. He just used it to do the counting of oranges trees in California, the number of fruit sets. Of course, they can only count what they can see; they were able to actually do a very good counting and creating a fruit count map using UAVs. They use a very low flying UAV that goes between the rows to count them and they actually use a combination of two or three of them. They use one robot that looks over the top of the trees and two to go along the sides of the tree and they go together. We just received funding from the National Aquatic Initiative to use a similar approach to look at blueberries and peaches.

Another application is detecting drainage problems. This picture is from Ohio (Fig. 18). They put this drainage line in back in the 1950s, back then it was costly for them to put drainage closer together so they put it fairly far apart. Now they have learned that those drains are not draining very well and they want to put a new drain line along the old ones, the problem is they don't know where the old ones are to put in the new ones. So this picture shows that if you take an image at the right time, let's say after a 24-hour rain event, you can see easily the water absorbed back into the ground by the dark areas, now you can see the lines where they are, you can go back to that field and put in the new lines. So this is another application that can be used with UAVs.

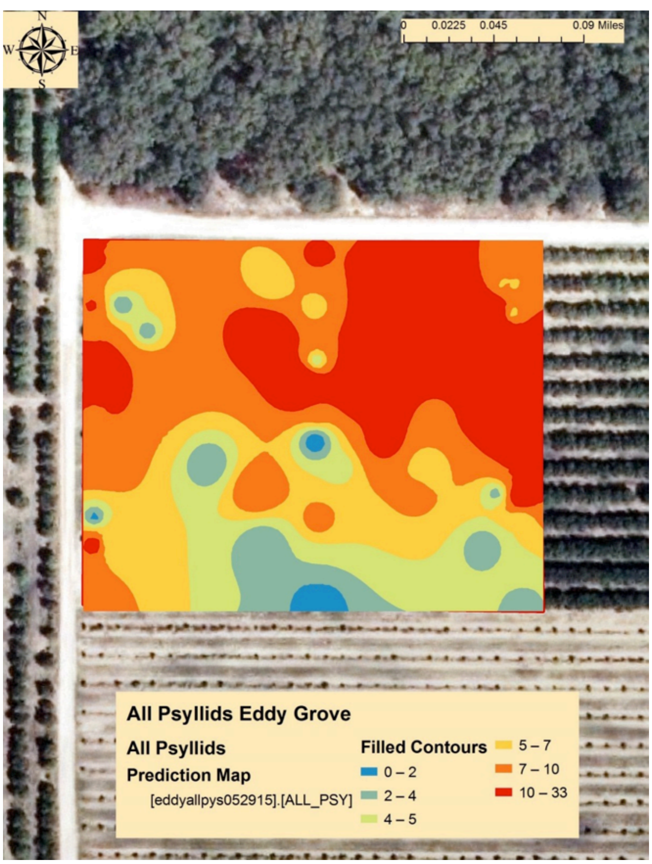

Fig. 17. Using UAV imagery for insect mapping.

Fig. 18, Detecting old drainage lines by using UAV imagery.

I'm going to touch a little bit of growers' perspective because it is important to know what the growers think. We received a planning grant last year with Georgia Institute of Technology, the University of Georgia, and part of this planning grant was "Harnessing Unmanned Aerial Vehicles in Fruit, Vegetable, and Nut Crops". As a part of that planning grant we were able to survey growers and to learn what they think is important about the use of UAV in their operations. So we talked with three groups of growers; pecan growers, blueberry growers, and peach growers. One of the questions we asked was "How much thought have you given to the potential use of UAVs ('drones') in your crops?" The response of all the people that participated was the majority have given some thought to UAVs compared to those who haven't overall. But when we look at this by crops, for example, blueberry growers are more interested about the use of UAVs than growers of peaches and pecans.

Then we looked at small vs. large farms, large farms being more than 300 acres. The large farm operators are more serious than those with smaller farms when it comes to the use of UAVs in their operation. Another question we asked was "What is your overall assessment of the value of UAVs in your crop of interest in the near future?" They are predicting that this has more influence on them and the majority of them thought that this is going to be very useful for their operation. The growers were also asked "Where do you see the highest potential value of UAV use in your operation if the technology were available and affordable?" The things that they felt were most important were stress/disease detection, water stress detection, detailed plant scouting, yield/maturity estimations, and there were some other categories also listed such as worker surveillance but not many of them were interested in that. When you look at each crop individually, you can see that the top four pretty much remained the same.

So in conclusion, we can see that at least 80% of the growers surveyed have given UAV application at least "some thought"; 95% of those surveyed have considered UAVs at least "somewhat useful" for their operations. The percentages depended on farm size and were highest for blueberries with 75% of them finding it "very useful". Regardless of the crop the ranking of the top four applications priorities remained identical.

So let's talk a little bit about the rules and regulations. At the current time, UAVs cannot be legally used for commercial uses. They can be used for hobby purposes, but legally, no one is allowed to use it commercially unless you have certification or license from the FAA or get a special exemption.

The following are the proposals and we expect that we should have them approved by the end of 2016 and in use by 2017. The current rules are universities can apply for COA and other proposed regulations for small UAVs: small UAVs—55 lbs. or less; the operator must be older than 17 years of age with training certificate, must be in "line of sight"; used only during the daytime (which is a shame because we get great spectrographic images at night); out of airport flight paths; and below 500 ft.

In summary, UAV [technology] has created a lot of potential applications in agriculture and horticulture crops, especially with small farms. More research is needed into UAVs for specific uses, developing tools, and techniques. The governmental rules and regulations—some are clear but some are not. There is excitement among growers and one thing that is important is that this is enabling technology. This is a technology that is like the cell phone; it's going to change the way we operate. And the next step, I believe, will be the use swarms of UAVs, with different types of sensors and they will communicate with each other do multiple things in the field.

I want to thank you for listening and I hope you enjoyed my presentation.