Oregon Department of Agriculture

FINAL Progress Report

Project title: Automation of plant inventory processes using an aerial systems approach

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Collaborating nurseries: J. Frank Schmidt & Son Nursery, Bailey Nurseries, Woodburn Nursery & Azalea

Significance to Industry/Summary:

A multi-rotor aircraft is now in place in Oregon for performing future work on inventory management and crop monitoring for open field nursery crops and Christmas trees. A multi-institutional and multi-state team has been involved in acquiring and analyzing digital images using a commercially available 'object based' (OB) software package. Recent research suggests that object based image analysis (OBIA) approach provides superior classification results for high spatial resolution images compared to traditional image processing approaches that were developed to analyze coarser resolution images acquired through satellites or aircraft. The output from the high resolution processed images was subjected to 'filtering' and manual editing before arriving at the final plant count. The results indicate the potential of pursuing OBIA approach for analyzing representative nursery crops and Christmas trees. Further work is required to develop an OBIA based system that it is adoptable in a production setting.

Accomplishments:

1. Entire research team met in Oregon for training & planning (5/2 to 5/5/11)
2. Flew training, demonstration, and data collection flights
3. Purchased components & re-built a 6-rotor multicopter as a result of a crash on 6/22
4. Collected data at cooperating nurseries on crops of different age, size and canopy structure.
5. Gave presentation at Farwest Seminars and ANLA Kick the Dirt (8/25/11)
6. Conducted a survey on inventory management practices in the nursery industry (8/25/11)
7. Processed and analyzed digital images using object based software
8. Submitted a $1,277,338 Specialty Crop Research Initiative grant in January 2011. (not funded).
9. Created an enhanced to website to report progress of the project to stakeholders (http://www.aragriculture.org/horticulture/nursery_automation/default.htm)
10. Met with FAA to discuss current and future research and commercial regulation (12/06/11)

Project background and/or justification:

Collection of real-time inventory data is expensive, time consuming, and often imprecise. As a result, nurseries and Christmas tree growers often use estimates to determine current availability. For the past two years this team has been pursuing a range of cost-effective sensors to obtain inventory data for both field and container nurseries. In June, 2010 this collaborative team identified a multi-rotor system (MRS) that can be used as a low cost platform to collect digital imagery. In addition to assisting with inventory management, the low cost system has the potential to be used in the future for other facets of nursery management such as identification of weed or pest pressure or to determine abiotic (e.g. poor soil conditions) or biotic (e.g. spider mites) stress on an 'as needed' basis.

Modified Project objectives:

The collection of real-time inventory data in varying nursery production systems using an unmanned aerial vehicle is collaborative effort between University of Arkansas, University of Florida and Oregon State University. The goal of this collaborative team is to develop a cost-effective, low altitude aerial imagery system, to automate inventory processes at shade tree nurseries, container nurseries, and Christmas tree farms. The specific objectives are: (i) evaluate sensor (camera) parameters such as field of view and altitude on image quality, (ii) evaluate the effect of environmental factors such as shadows, and (iii) process and evaluate all images collected in the preceding for counting accuracy.

Methods:

The MRS (Basicset Hexa XL with MD 2 Camera Mount) utilized in the current research was assembled from components purchased via Mikrokopter store (MiKroKopter US, Watsonville CA). The hexa-copter is capable of vertical takeoff and landing in a manner similar to a helicopter, which allows it to be launched and landed with ease on varying terrain. The MRS is also capable of being flown using a commercially available multi-channel remote control (R/C) transmitter and has the ability to lift a payload of approximately 0.9 kg (2 lbs). It uses Lithium Ion Polymer (LIPO) batteries as its power source and depending on the load and battery capacity has a flight time of 8-24 minutes. The camera mount (MD 2 Camera Mount ,MiKroKopter US, Watsonville CA) installed on the MRRSS platform is controlled by gyros which maintain the camera or other sensing device perpendicular to the production surface. This camera mount position can be controlled using the R/C transmitter. The MRS control system consists of an on-board and a ground station subsystem. The on-board navigation system, using low cost inertial sensors, pressure sensor, GPS and a computer, is capable of providing continuous estimates of the MRS in flight position (latitude, longitude, and altitude). The on-board computer records flight details in a KML file format that can be visualized using Google Earth. The ground station subsystem serves as an interface between a human operator and the MRS to implement mission planning, flight command activation, and real-time flight monitoring. The navigation system also accepts GPS waypoints (a reference point used for purposes of navigation) preloaded before flight or in-flight acting as auto-navigation while in flight. This navigation system also allows the user to easily retrieve the MRS while in flight and has the capability to go back to its specified starting position.

The mounted camera/sensor can be activated at pre-determined interval or by the user using a radio control transmitter. The ability to save and upload waypoints is especially important as it allows ease of repeated flights for temporal comparison of previously collected data. This platform could potentially be used on an "as needed" basis by growers. Other advantages of this platform are its low turnaround time for providing acquired imagery (becomes available after landing the unit); high spatial resolution, and the ability to obtain the image at any desired point in time.

Imagery was collected at both a container and field nursery. A Christmas tree farm was also included at project initiation. Aerial images were taken at Bailey Nurseries, Yamhill, OR and J. Frank Schmidt & Son Nursery, Canby, OR using a Sony NEX-5 camera with a Sony SEL 16mm f/2.8 wide-angle lens (Tokyo, Japan). The MRS was flown at three altitudes (115, 200, 280 feet) above a production sheared and unsheared plants of varying size and consequently different spacing. Three photographs were typically taken at each altitude for each plant. Orange cones that were visible in the images were placed on the ground to mark the area of interest. The number of plants within this marked area was counted once by an individual prior to flight. Three or more photographs were taken at each elevation above the area of interest. The images from each altitude were viewed manually and an image with optimal image focus and field of view was selected to be analyzed using OBIA approach.

The OBIA approach was adopted to extract plant information in a two-step process involving image segmentation and classification based on spectral and contextual information (Blaschke and Hay, 2001). Segmentation resulted in vector boundaries of individual plants and, combined with spectral values for each plant, and contextual information between plants, thematic classification was generated by applying Feature Analyst v.5.0 for ArcGIS software (Overwatch Textron Systems, Austin, TX, USA) to the selected image. A genetic ensemble feature selection (GEFS) neural network algorithm (Blundell and Opitz, 2006) was implemented in Feature Analyst, for plant classification. The algorithm created a boundary file around objects of interest using the contextual and spectral information provided in the form of training sets. Our initial segmentation generated vector boundaries for image objects that included plants, overlapping plants and shadows. The total number of plants, in the initial run, was greater than the actual numbers counted in the test area. An iterative process available within the software was used to improve on the initial run. The end point for the iteration process was signaled, beyond which the number of plants obtained through classification process again started to increase. At that stage, the resultant polygonal shape files was converted to point shape files and the numbers of points designating plant positions were manually counted.

Data collection flights (6 flights, 214 aerial images)**:**

Plant Type	Elevation above ground, ft	Total Plants (ground truth)	Computer generated count	Missed Plants	Double Counts (same plant)	Triple Counts (same plant)	More than triple count	Unclassified (e.g. weeds)	Net Count Accuracy[Z]	Overall Count Accuracy[Y]
Christmas Tree (unsheared)	**150**	**88**	**88**	**1**	**4**	**0**		**0**	**95**	**94**
	200	**88**	**87**	**0**	**0**	**0**		**2**	**99**	**97**
	280	**88**	**87**	**1**	**1**	**0**		**2**	**98**	**95**

Pyrus	**115**	**190**	**179**	**18**	**7**				**91**	**83**
	200	**190**	**192**	**16**	**18**				**92**	**84**
	280	**190**	**191**	**1**	**2**				**99**	**99**
Barberry	**115**	**850**	**864**	**23**	**35**	**1**			**97**	**95**
	200	**850**	**821**	**52**	**23**				**94**	**88**
	280	**850**	**824**	**27**	**1**				**97**	**94**
PJM #1	**115**	**1444**	**392**	**1103**	**34**	**5**		**7**	**24**	**14**
	200	**1444**	**740**	**717**	**8**	**0**		**5**	**51**	**34**
	280	**1444**	**276**	**1179**	**0**	**0**		**11**	**19**	**10**
PJM #2	**115**	**844**	**626**	**475**	**101**	**26**		**58**	**56**	**34**
	200	**844**	**301**	**554**	**5**	**0**		**6**	**35**	**21**
	280	**844**	**441**	**418**	**14**	**0**		**1**	**51**	**34**
PJM #5	**115**	**444**	**1023**	**66**	**90**	**70**	**110**	**17**	**85**	**72**
	200	**444**	**343**	**122**	**20**	**0**		**1**	**73**	**57**
	280	**444**	**103**	**350**	**9**	**0**		**0**	**21**	**12**

[Z]Net count accuracy: measure of all the plants correctly identified through OBA approach compared to manual count

[Y]Overall count accuracy: measure of overall accuracy of OBA approach by including missing as well as unidentified points on the analyzed image

Results and Lessons Learned:

The MRS is a robust vehicle that can be utilized to take aerial imagery. The largest limitation to the MRS is it remains a hobby vehicle using communications hardware and freeware from the radio control hobbyist arena, therefore, both need additional development to be commercially viable. Initial training and education of the multiple software packages and understanding of hardware is more time consuming than initially thought. Basic understanding of electrical components, communications and geospatial software must be learned for successful use of MRS. The MRS exceeded expectations in ability to collect imagery up to 300 feet high, 820 feet from pilot, and hold position (GPS location and altitude) under winds from 10 to 15 mph. Time of flight, 8 to 15 minutes, is temperature and wind dependent. This flight time allows pilot to capture replicated still images of approximately 15 or less waypoints. Multiple flights would have to be conducted to capture larger areas, camera and lens dependent, using still images. If video proves successful, this will potentially allow greater acreage covered per flight by having continuous data collection when airborne and not requiring the MRS to remain stationary for image collection.

The MRS cost is estimated to be equal or greater than $10,000 dollars excluding the camera. Inexpensive point and shoot cameras may not be suitable for use with the platform because of a limited field of view and poor resolution allowing only 60% of picture usable for data collection. Furthermore, poor resolution in images is an obstacle to creating a composite or mosaic image of the farm or area of interest. Currently the research team is investigating the use of professional cameras with wide-angle lenses to increase resolution and decrease the number of pictures needed to create a mosaic image of the farm or area of interest. Another avenue being pursued by the PIs is to use HD video to collect pictures and create mosaic images.

Imagery of in-ground bare root shade trees was omitted from data analysis because it was deemed challenging for inventory process at this time. Initial imagery taken of bare root shade trees examining time of day to collect imagery provided useful, due to images showing shadows as a potential usable mechanism to count trees in the future, however PIs have not pursued this currently. Certain container-grown plants (Pyrus and barberry) could be counted with 83% to 99% (see overall count accuracy). Accuracy is primarily a function of camera resolution and size of discernable void between plant canopies. There appears to be little relationship to altitude and count accuracy, however, the team would like to proceed with properly designed experiments in future to investigate this relation more thoroughly. The containerized rhododendron provided the largest challenge to count aerially with lowest overall count accuracy (see included pictures for examples of collected imagery and algorithm counts).

In the 2011 field season, a multi-rotor aircraft was assembled and images were collected in various crop types and scenarios, capturing different growth patterns, stages, and spacing situations. From these data sets we were able to test the MRS platform, data collection methods, and commercially available image processing software with many successes. In many scenarios, highly accurate inventory counts were made, especially after further optimization of the image processing algorithms. Although the research season also lead to the discovery of some limitations of the MRS system, future work aims to focus on further refining the use of the MRS, including the use of video to capture larger field areas, the collection of more images for analysis and further work with image processing systems.

Training flights (4):

5/3/11: Woodburn Nursery & Azalea

5/4/11: J. Frank Schmidt & Son – Canby Farm

5/4/11: Bailey Nursery – Yamhill

6/22/11; Bailey Nursery – Yamhill; 21 images

Demonstration flights (3):

5/5/11: Media Day at J. Frank Schmidt & Son Nursery, Boring. Resulted in article in Oregonian: *http://www.oregonlive.com/environment/index.ssf/2011/05/oregon_nurseries_explore_unman.html*

8/23/11: Farwest Nursery Tours; NWREC

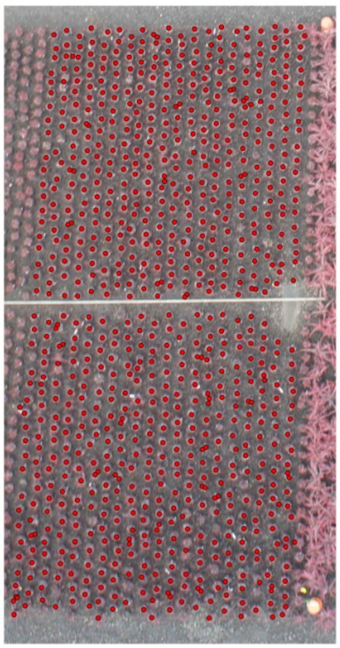
8/24/11: Gold Hill Nursery; demonstration for OAN/ODA liaison, Steve Gold

9/14/11: OSU Nursery Field Day; NWREC

Bailey Nursery – Yamhill; 8/11/11

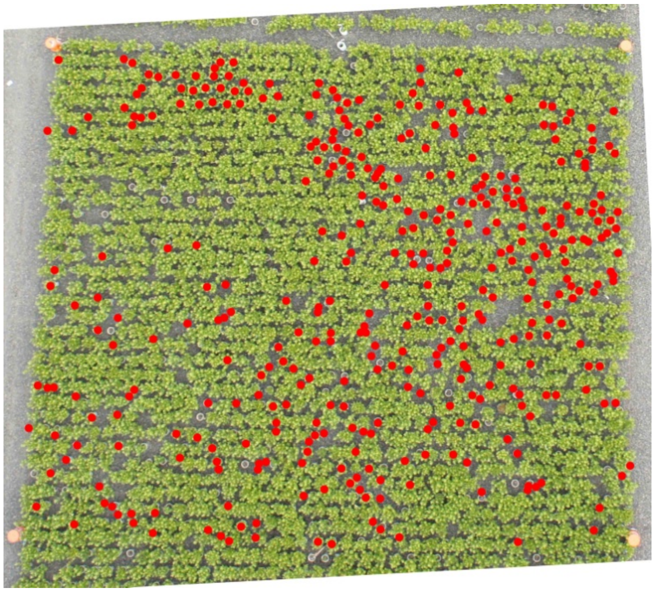
Barberry 'Rose Glow' (#1 & #2)

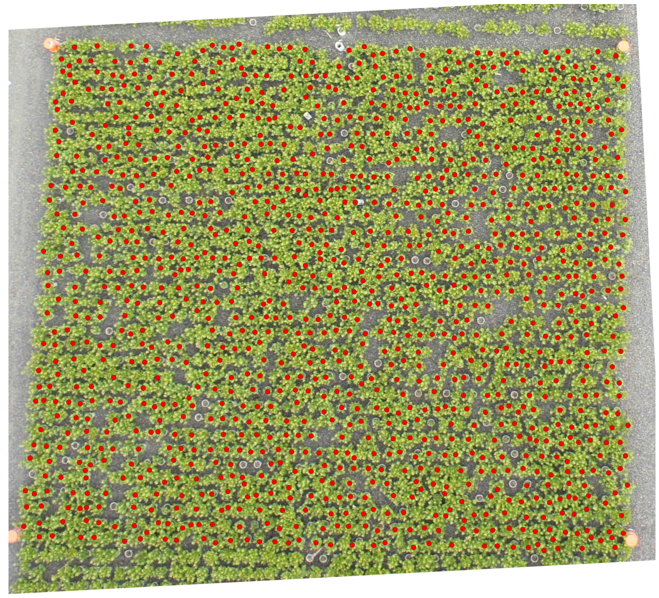
Example of analyzed aerial image (red dots indicated plant 'counted'):



#1 container; 115 ft

Picture 2: Example of analyzed aerial image (red dots indicated plant 'counted') PJM Rhododendron (#1, #2 & #5)



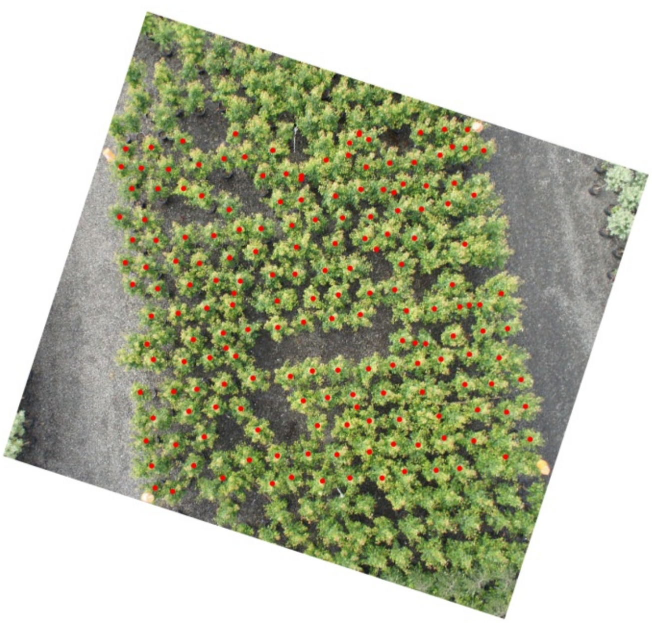


#1 container; 115 ft

(same block re-analyzed using ‘improved’ algorithm)

Pyrus ‘Autumn Blaze’ (#10)

Example of analyzed aerial image (red dots indicated plant ‘counted’):



#10 container; 115 ft

Aerial images for Prunus ‘Pink Snow’ (#10) and ‘Royal Frost’ Birch (#10) have not been analyzed since the overlapping canopies do not lend themselves to the current approach of ‘counting’.

J. Frank Schmidt & Son – Canby Farm; 8/3/11

Field-grown 1yr whip ‘Red Pointe’ maples and 2yr branched ‘Red Pointe’ maples

Images from these flights were analyzed, however, our current approach to ‘counting’ will need to be modified based on future research to deal with this type of production situation.

Yule Tree Farm; 8/5/11

Aerial images of un-sheared Douglas-fir:

Example of analyzed aerial image (red dots indicated plant ‘counted’):

115 ft