Final Research Report entitled

CONTINUED DEVELOPMENT OF AN AERIAL SYSTEM TO COLLECT COMPOSITE OR SINGLE VISUAL IMAGES FOR INVENTORY MANAGEMENT

OREGON ASSOCIATION OF NURSERIES

and

NURSERY RESEARCH AND REGULATORY COMMITTEE

Principal Investigators:

Dr. Chal Langren and Heather Stoven
Oregon State University, North Willamette Rsch. and Ext. Cntr.
15210 NE Miley Road, Aurora, OR 97002; 503.678.1264
chal.landgren@oregonstate.edu

Drs. Reza Ehsani and Joe Maja
University of Florida, Citrus Research & Education Center
700 Experiment Station Road, Lake Alfred, FL 33850
ehsani@ufl.edu

Dr. James Robbins
University of Arkansas - Cooperative Extension Service
2301 South University Avenue, Little Rock, AR 72204
jrobbins@uaex.edu

Project Coordinator

Dr. Jim Owen, Virginia Polytechnic Institute and State University (Virginia Tech)
jim.owen@vt.edu; 757.374.8153

Industry Cooperators:

Sam Doane, J. Frank Schmidt and Son, Co.
Marlin Brethower, Bailey Nurseries, Inc.
Jim Puffer, Yule Tree Farm

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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 frequently rely on estimates to determine current inventory. In June 2010 this collaborative team identified existing hardware and software that could be integrated to create a multi-rotor remote sensing system (MRRSS). This system has the potential to be 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 crop monitoring and aid in management decisions. In 2011, the research: (i) evaluated a point-and-shoot Sony camera at 3 altitudes up to 279 ft (ii) looked at time of day to collect photos to better understand the impact of light and subsequent shadows in winds up to 12 mph (iii) and, to date, began processing collected images to identify limitations and conditions in which accurate counts can be provided with ease.

Project objectives:

The collection of real-time inventory data in varying outdoor plant production systems using a MRRSS is a 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 field and container nurseries, and Christmas tree farms. The specific objectives for this grant are: (i) determine the feasibility of stitching images from two camera types: **inexpensive, point-and-shoot and inexpensive, digital video camera** (ii) continue development of imagery database and (iii) count plants in images from cooperating nurseries/fields using commercially available software and a digital counting pen.

Overview of methods and timelines:

A **low-cost, non-professional-grade still and video digital camera** will be purchased and utilized to collect multiple or single images at test sites. This will necessitate upgrades in the MRRSS hardware and communication systems. The area photographed will represent a definable area of interest as specified by the cooperator. Examples may include whole field, entire crop, or management unit. The location of the camera and its altitude shall be controlled by GPS receiver and microprocessors on the MRRSS platform, respectively. Ambient light and wind speed will be measured using appropriate sensors. Acquired images shall undergo standardized image pre-processing using commercially available software before creating a seamless image for the study area. Stitched and single images will be analyzed for plant count using licensed software and an inexpensive manual digital counting pen. The results will be validated and compared to ground based counts.

Benefit to the Nursery Industry:

Currently, collection of real-time inventory data is expensive, time consuming and an often-imprecise procedure for growers of any kind. Automating this process would reduce labor inputs, increase process accuracy, reduce workforce strain associated with this manual activity, provide and result in substantial monetary savings for plant producers. Secondly, imagery can be used to spatially understand location of infrastructure (roads, buildings, irrigation) and could potentially be used as a real-time diagnostic tool to visually identify regions of concern that should be further investigated.

Accomplishments:

1. The Florida, Arkansas and Oregon team members successfully passed the private pilots ground school and Class 2 medical exams and completed the required FAA Certificate of Authorization (COA) allowing for UAV flights for each of these groups.
2. Improvements made to UAV: new receiver, firmware and software allowing for greater stability and accuracy by having GPS controlled flight altitude.
3. Fine tuning of analysis of images by graduate students in Arkansas using off the shelf software and Florida in development of new algorithms.
4. Collection of images in Florida and Virginia by the Arkansas, Virginia and Florida team members with a fixed platform using thermal, multi-spectral and visible imagery at varying spacing on gravel or fabric.
5. Collection of still and video images in Christmas trees in Oregon at different altitudes
6. Collection of video images in a container nursery in Florida
7. Multiple presentations and publications about the project including:
    a. IPPS Southern Region, Oct, 2012
    b. Southern Nursery Association paper, August 2013
    c. Presentation at the American Society of Agricultural and Biological Engineers meeting in July, 2013
    d. Paper at The Asian Precision Agriculture Conference, June 2013
    e. Presentation at Gold Nursery Field Day, Sept. 2013

Overview:

In November of 2011, a faculty member at the University of Arkansas not associated with the OAN/ODA project was notified by a regional specialist of the Federal Aviation Administration (FAA), that they were ‘using the Oktokopter without proper authorization’. In response to that notification, five members of the research team met on December 6, 2011 with officials from the FAA’s Unmanned Aerial Systems (UAS) office in Washington, D.C. to discuss the reasoning and needs of the required credentials. The FAA officials informed the team that public institutions wishing to fly unmanned aircraft must follow the ‘Interim Operational Approval Guidance 08-01’. In summary, this interim guidance requires that an unmanned aircraft flown by a public institution be flown by a pilot and observer both of whom have passed a ‘private pilots ground school’ and a Class 2 Medical exam. Each aircraft is also required to have completed a Certificate of Authorization (COA) in part authorized by the state Attorney General in which the research will be conducted. Since January 2011, each institution has fulfilled all FAA requirements. Meeting FAA requirements has been an unexpected challenge for the research team; however the team remains steadfast to meet the ‘interim’ guidelines. The FAA is working on drafting formal Flight Aviation Regulations (FAR) to provide ‘full integration of UAS into US national airspace by 30th September, 2015. Furthermore, the research team is maintaining an open dialogue with the FAA on future regulations for use of ‘domestic drones’ in agriculture.

In the interim, University of Florida and Virginia Tech conducted ground-based research using an articulating boom to investigate the use of thermal, multi-spectral and visible imagery to increase accuracy of the algorithm to identify individual plants at varying spacing on gravel or fabric. In addition, co-PIs Drs. Ehsani and Owen were able to validate the concept of using multispectral and/or thermal imagery to identify plant stress (water and/or nutrient) from aerial imagery. This research was conducted in June, 2012 in Virginia and was repeated in November 2012 in Lakeland, FL where researchers continued investigating the use of a fixed and aerial platform to collect imagery for use in inventory of shrubs at varying spacing and height. In addition, Drs. Ehsani and Owen utilized visible and multispectral imagery and radiometer data collected with the fixed platform to determine the best method to detect poor canopy color or nutrient deficiency.

In June, 2013, Oregon State University conducted three flights collecting still images and video imagery at Christmas tree farms in the Northern Willamette Valley of OR. The University of Florida team also collected video imagery at a Florida container nursery in August, 2013. This and additional imagery collected the fall/winter of 2012 was analyzed to determine the most efficient method to collect and process images to create a composite image of an individual farm to be used in quantifying inventory. In addition, the University of Arkansas had a Master’s student begin in August, 2012 who is focused on ‘inventory management’ in open-field nurseries.

Results and Lessons Learned:

The plant density and thermal imagery experiments were conducted on 13 and 14 November, 2012 at the Citrus Research and Education Center (University of Florida, FL, USA). A block of 100, # 1 containers were spaced in a 10 × 10 square grid. Containers of perennial peanut (*Arachis glabrata* Benth), a containerized southeastern ornamental crop, were positioned on black polypropylene fabric.

A 60 foot articulated boom was used in this study. A Canon EOS 5D Mark II camera (5,616 × 3,744 pixels) was mounted to an aluminum pole that extended 2 m horizontally beyond the bucket. The camera was triggered remotely. Photographs were taken at an elevation of 30, 40, 50, and 60 ft. For each boom height, plants were spaced to obtain 0.8, 1.1, 1.6, 2.5 and 3.3 plants per square foot.

The overall accuracy of the peanut count was 97.6% (Table 1). Except for a plant density of 2.5 plants/ft^2, there does not appear to be an affect of boom height on counting accuracy when images are analyzed using Feature Analyst. For a plant density of 2.5 plants/ft^2, lowering the boom height from 50 to 30 feet (increasing spatial resolution), caused a decrease in counting accuracy. Across all plant densities and boom heights, there does not appear to be a consistent trend related to plant count accuracy, however the lowest count accuracies were observed for a plant density of 1.6 plants/ft^2.

Table 1. Effect of plant density and boom height on plant counting accuracy

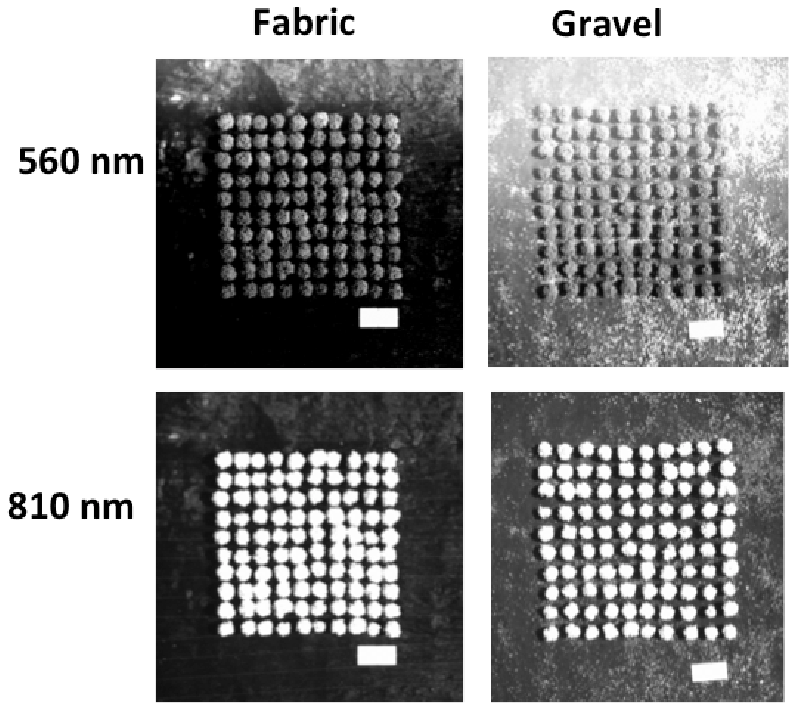
Boom Height (feet)	Plant density (Plants per square foot) 0.6	0.8	1.1	1.6	2.5	Overall Mean
30	100.0	99.0	99.7	93.6	90.1	96.5
40	100.7	101.3	100.0	91.0	91.7	96.9
50	100.0	100.3	100.0	91.3	100.3	98.4
60	100.0	99.4	99.5	91.7	103.3	98.8
Overall Mean	100.2	100.0	99.8	91.9	96.3	97.6

*Values are expressed as percentages.

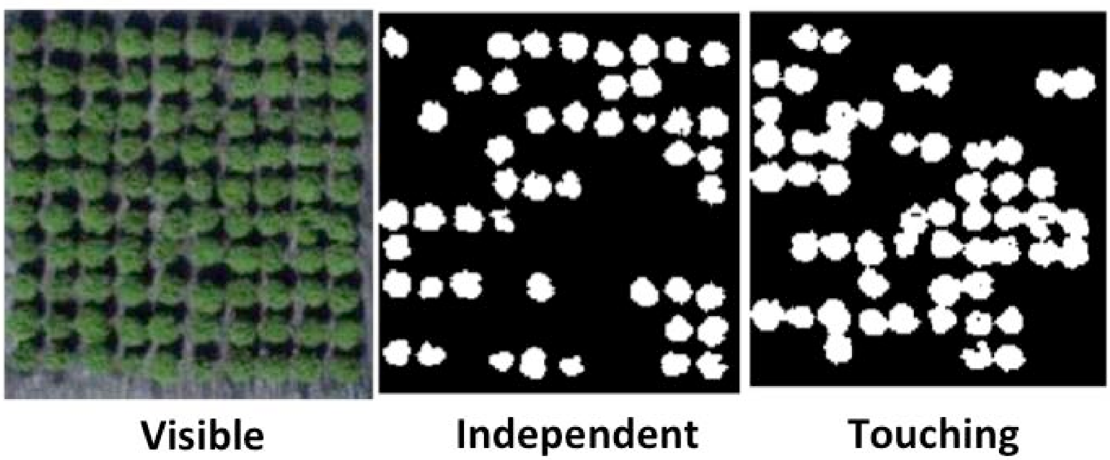
Image of research conducted at Virginia Tech in Summer 2012.

Images of research conducted at University of Florida in Fall, 2012.

Example of thermal imagery used to detect drought stress. Visible image shown on the left and thermal image is on the right. A block of 12 plants in the left corner of the thermal image appear lighter, indicating plant stress, but water stress is not detected in the visible image.

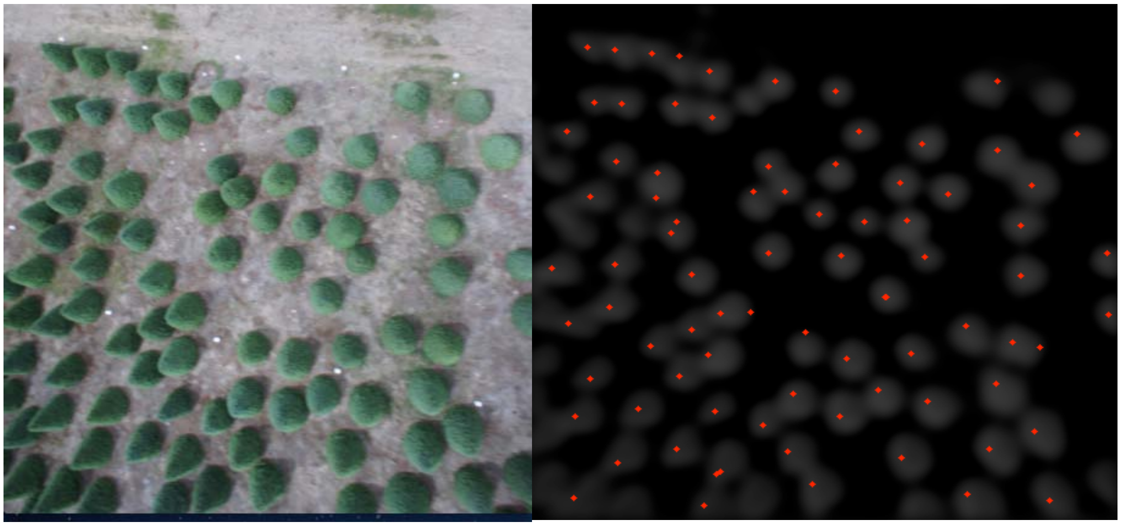


Multispectral imagery at 560 and 810 nm that can potentially be utilized for improved counting accuracy.



Visualization of new algorithm created by the University of Florida using green index and counting plants if not touching (independent) and canopy when touching (touching) separately resulting in 95% accurate inventory estimation.

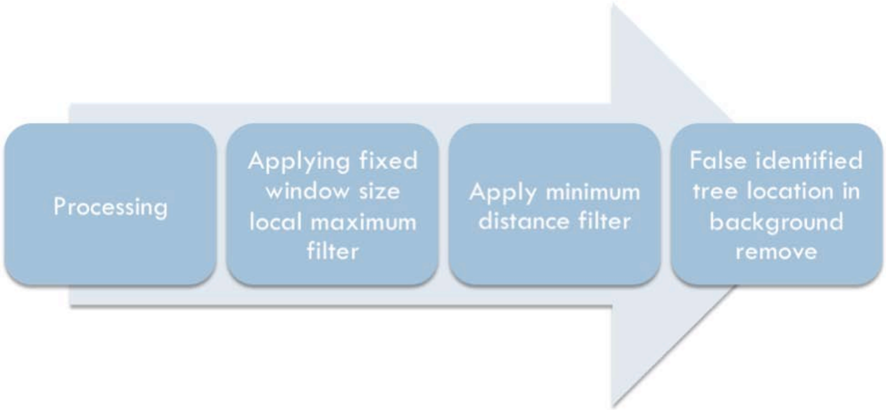
On June 11, 2013 still and video images were collected on a Christmas tree farm in Marion County. Flights were flown at 35 m and 45 m altitude.



Actual Counting=86 Algorithm counting=83

Actual Counting=74 Algorithm counting=76

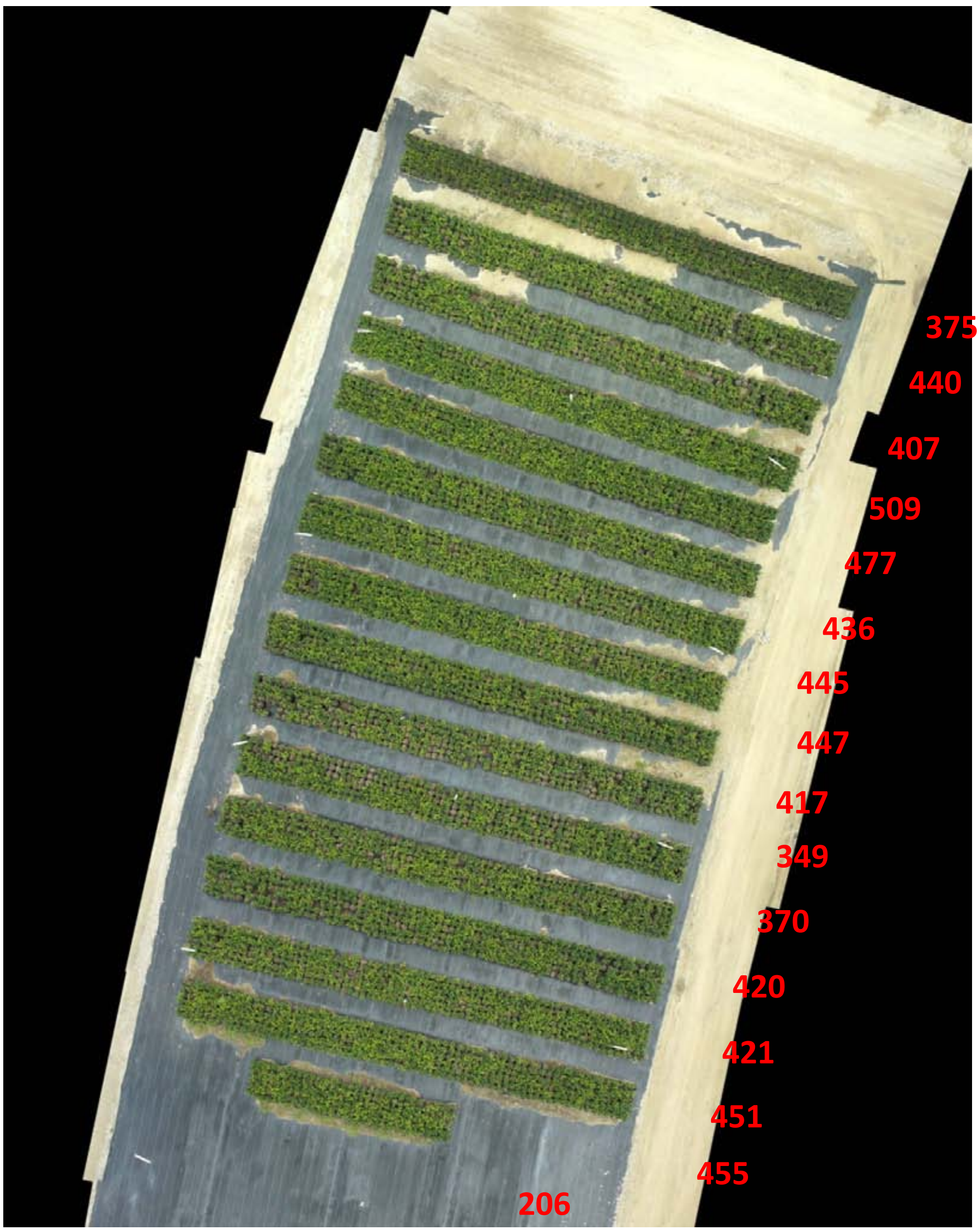
The University of Florida analyzed the Christmas tree images using their own algorithm. An image processing algorithm was developed that uses the fact that tree reflectance occurs with a maximum value at the center of the tree. This special characteristic in Christmas trees is used to identify the individual trees and count them in an aerial image. For conifers, a local maximum filter is used. A window with fixed or variable size will pass over all the pixels and check if a given pixel is with higher reflectance than other pixels within the window. Pixels with the largest digital number in the window will be marked as a tree location. In order to identify individual trees, multiple filters are applied. This balances out errors from trees in close proximity being identified as one tree and single trees with a large canopy being identified as two or more trees.



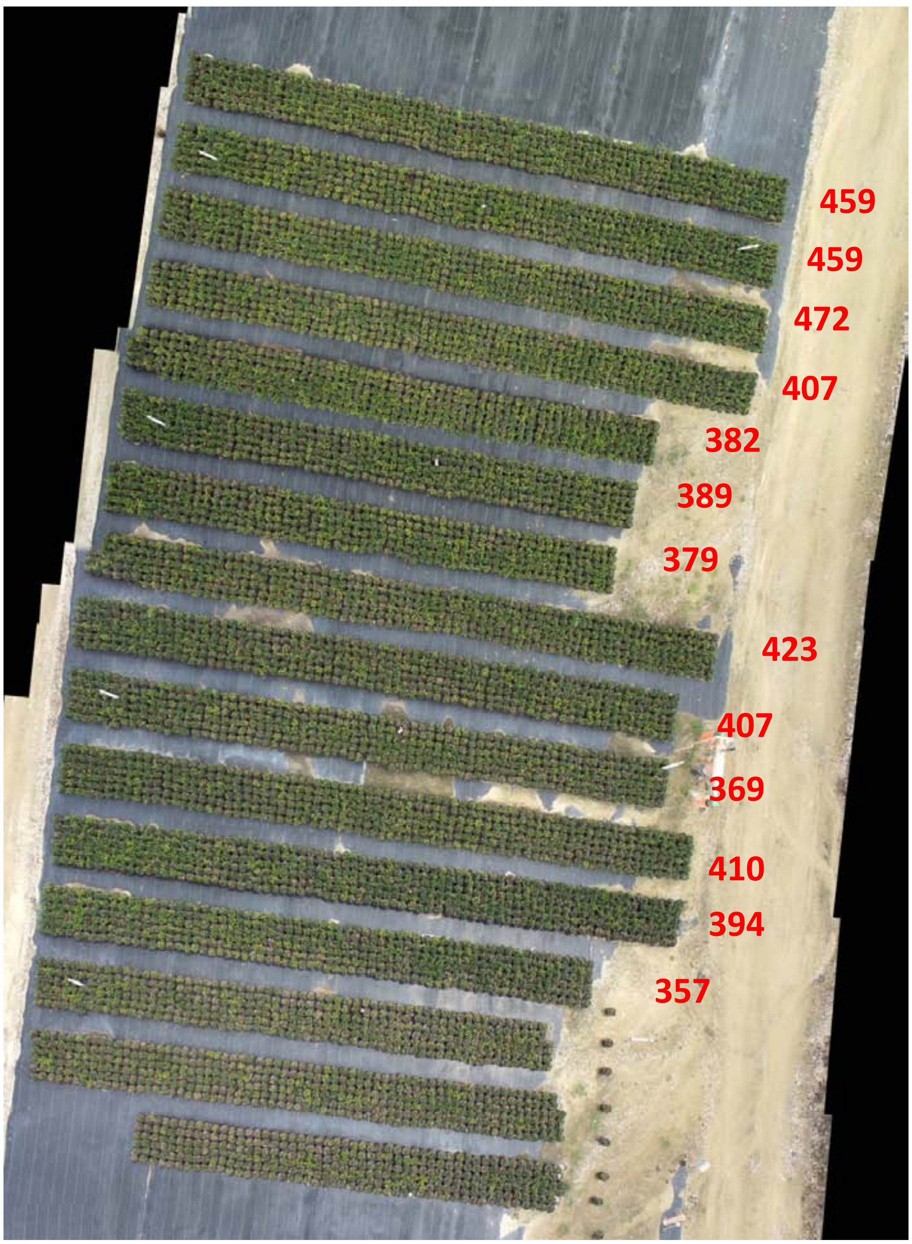
Algorithm methodology flow chart

Aerial images were taken in Florida with a video camera in August, 2013 on 3 gallon *Ilex cornuta* 'Burfordii' and *Viburnum obovatum* 'Mrs. Schiller's Delight'. Video was collected from the multicopter flying over the length of the block at an altitude of 17m. The images below were stitched with ICE software with the count data shown to the right of the image in red lettering. Of roughly 22,000 plants in the 3 stitched images below, the number of plants counted from the video images was within 2% of the actual count. The algorithm was able to count plants with overlapping canopies successfully, demonstrating that video images can provide accurate counting data.

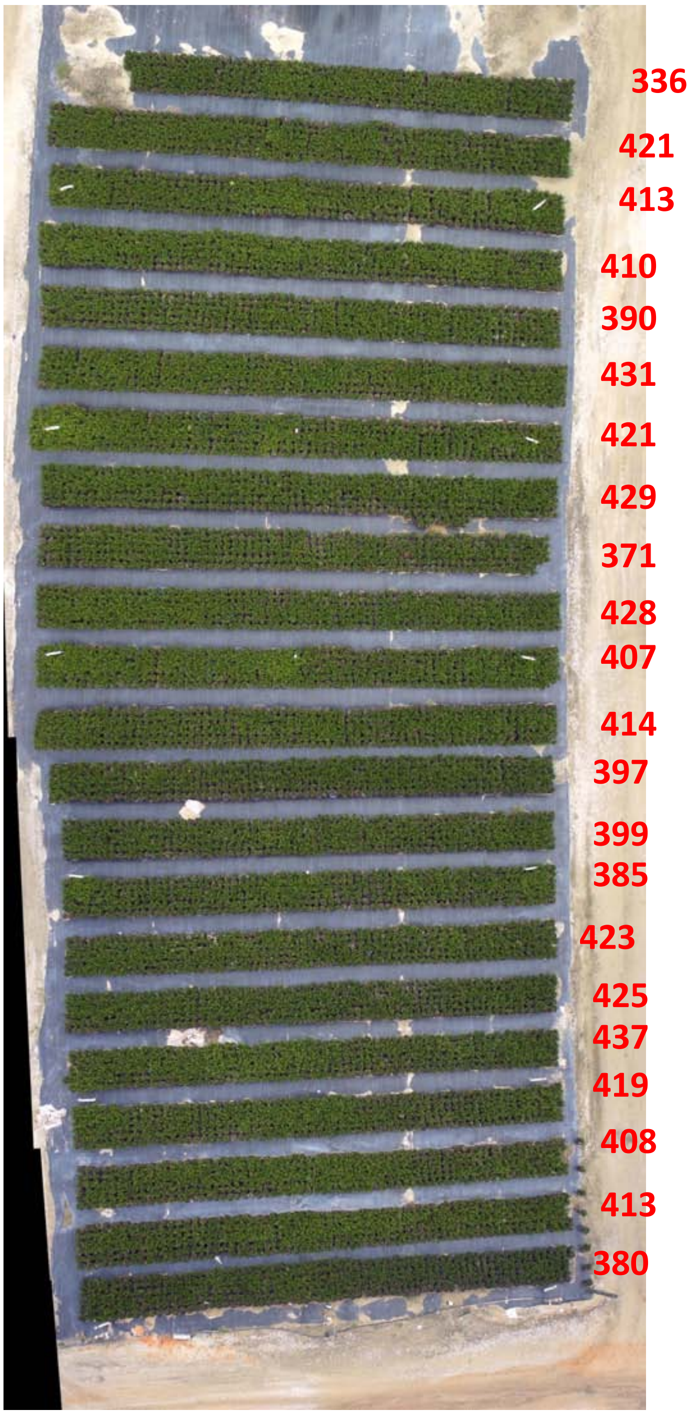
Training set:



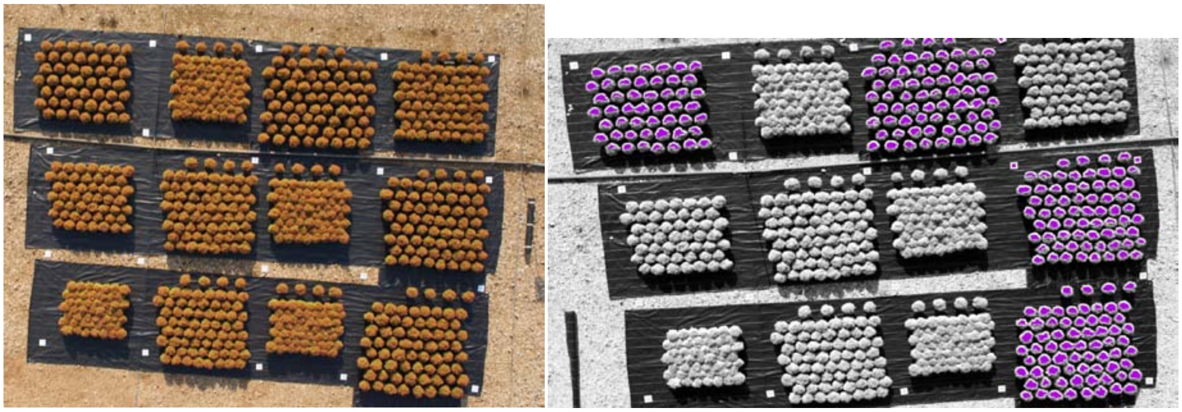
Training set:



Training set:



The University of Arkansas continues to collect imagery data from nurseries using 3 canopy separations and 3 altitudes on both fabric and gravel surfaces.



Effect of spatial resolution (flight altitude) and canopy separation on plant counting accuracy on black fabric & gravel for Thuja Fire Chief™

Table 2. Plant count for #3 Thuja Fire Chief™ (*Thuja occidentalis*) grown at three plant densities on black fabric ground cover using Feature Analyst® (FA). Photographs taken at 6, 12 and 22 m altitude above the ground.

Altitude m	Plant density plants/m2	Overall FA count accuracy (%)
6	8.8	95
6	11.9	77
6	17.6	121
12	8.8	100
12	11.9	81
12	17.6	101
22	8.8	100
22	11.9	93
22	17.6	88

Conclusions

New improvements made to the UAV allowed for more stable flights at preprogrammed altitudes resulting in more accurate counting data. Flights using still imagery in Christmas trees resulted in over 96% accuracy when analyzed with a newly developed algorithm. Images stitched from video in a Florida nursery was 98% accurate for plant count. At this time, using video imagery of containerized plant material is a promising method for collecting inventory information.

Further data collected using an articulated boom demonstrated over 99% count accuracy with plant densities of 1.1 sq ft or less at four boom heights. Plant densities of either 1.6 or 2.5 plants per sq ft resulted in an average of 91 and 96% accuracy, respectively when using Feature Analyst to analyze imagery. Images collected with multispectral and thermal imagery validated the use of this technology to count plant material as well as to detect plant stress.

Work continues investigating spatial resolution and canopy separation on different ground surfaces as well as image analysis with algorithms and off the shelf software.