PennState
College of Agricultural Sciences

PROPOSAL TRANSMITTAL

Date: 12/14/2018 **PSU Ref. No: 206163**

Title: Buy-and-Fly Orchard Management using Unmanned Aircraft(UA)

Submitted to: Patti Keller

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Proposed Project **1/1/2019 - 12/31/2019** **Total Project Request: $16,000**

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Please reference PSU Ref. Number in all correspondence.

Research Grant Proposal
to
State Horticultural Association of Pennsylvania (SHAP)

Title: Buy-and-Fly Orchard Management using Unmanned Aircraft (UA)

Personnel: Robert M. Crassweller, Horticulture, Penn State University (PI)
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Duration of Project: January 1, 2019 - December 31, 2019 (third year of three year proposal)

Objective for Year 1 - 2017

Develop UA flight procedures and software to identify and count fruit trees using GPS for inventory control. Results were reported to SHAP, published in Pennsylvania Fruit News and presented as a poster at the MAFVC.

Objective for Year 2 – 2018

Develop UA flight procedures and software for close range photogrammetry of fruit trees to assess blossom canopy coverage and crop load using RGB images and leaf canopy health using NDVI images. A brief description of results is provided below and a full report will be sent to SHAP.

Objective for Year 3 - 2019

Develop a general purpose database to track details per individual fruit tree (cultivar, date planted, pruning, spraying, health, harvest) based on GPS location to help quantify orchard management decisions, automate reporting procedures and determine return-on-investment (ROI) per tree

Justification:

This proposal is a direct response to SHAP Research Priority "AG ENGINEERING - Use of New Technology to Improve Data Collection for Decision Making."

Unmanned aircraft (UA) - commonly called drones - are a new technology that can quickly collect, quantify and record a variety of important data about orchards that many growers inherently measure by eye. Simple examples include location of nonproductive trees, quantity of blossoms in the spring, stress on trees in the summer and crop load in the fall.

This proposal is focused on apple trees using DJI aircraft but can be extended to other fruit trees and other UA. The DJI Phantom 4 Pro ($2000) with 5472x3648 pixel RGB camera is recommended.

Progress (Year 1):

Best practices were developed to enable autonomous inspection of orchards. Sample images from Year 1 shown in Figure 1 include an autonomous mission plan, an orthomosaic map stitched together from multiple UA images captured during the mission, the resulting digital elevation map (DEM) and a close-up view at 1 inch per pixel resolution showing missing trees.

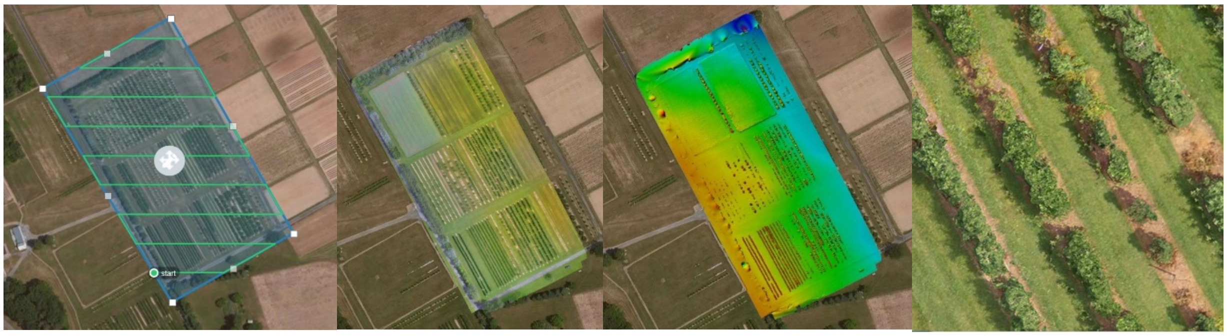

Figure 1 – Penn State Experimental Orchard at Rock Springs
(left = mission plan, left center = orthomosaic, right center = color DEM, right = close-up)

The seven leading mission planners were tested and compared based on 27 metrics. DroneDeploy mission planner is highly recommended. Additionally, the seven leading orthomosaic reconstruction services were tested and compared based on upload/processing speed, output resolution, output file format and cost-effectiveness. Maps Made Easy is highly recommended.

Three methods were developed and documented to georeference individual trees.
a) manual - hand-held GPS to locate posts and interpolate latitude/longitude for trees
b) software - identify posts in georeferenced TIFF orthomosaic and interpolate for trees
c) photogrammetry - use low altitude oblique photos to compute tree location based on GPS location, altitude and camera gimbal yaw/pitch of the UA

Progress (Year 2):

Blossom canopy:
Images of 20 apple trees in blossom at Rock Springs were captured at 50 feet above ground level (AGL) while the UA was flying sideways with the camera pitched down at 45 degrees to see the sides of the trees as shown in Figure 2. Image analysis quantified blossom canopy coverage (blossom area divided by total leaf canopy area), counted blossom clusters and measured cluster size/location.

Blossoms were also counted by hand for the same 20 trees. Blossom count data were correlated to image analyses from UA. Correlation results will be provided in the annual report.

Crop load:
Images of the same 20 trees at harvest were captured with the same flight procedures as shown in Figure 2. Software developed for blossom analysis was adapted to count apples.

Figure 2 - Same five apple trees photographed on May 14 and September 5 at Rock Springs

Number and weight of apples per tree were recorded at harvest for the same 20 trees. Crop load data were correlated to image analyses of apples Secondly, image analyses from blossoms were compared to image analyses of apples to identify if blossom location/size was related to fruit location/size. Lastly blossom measurement data were correlated to crop load data to assess quantitative prediction of yield from blossom canopy. Correlation results will be provided in the annual report.

Leaf canopy stress:
Normalized Difference Vegetation Index (NDVI) images from multispectral cameras allow identification of stress on vegetation caused by insects, fungi, diseases, wind, hail or lack of water. NDVI images were captured with a MicaSense RedEdge multispectral camera to monitor leaf canopy stress on apple trees at Rock Springs. Eleven mission were flown at 66 feet AGL over a four month period during summer 2018. A typical NDVI pseudo-color orthomosaic processed with PrecisionMapper software is shown in Figure 3 along with a traditional RGB orthomosaic. Healthy vegetation is colored green and stressed vegetation is colored orange in the pseudo-color image.

Unfortunately, detailed inspection of the eleven NDVI orthomosaics was not able to clearly identify individual tress that had significant stress compared to manual inspection. We believe that there are two reasons. NDVI measurements are very sensitive to incident illumination and

PrecisionMapper does not use illumination data available from the RedEdge down-welling light sensor (DLS). Secondly, the Rock Springs orchard is maintained in pristine condition and minimal stress was present. These tests will be repeated in 2019 with different NDVI orthomosaic processing software.

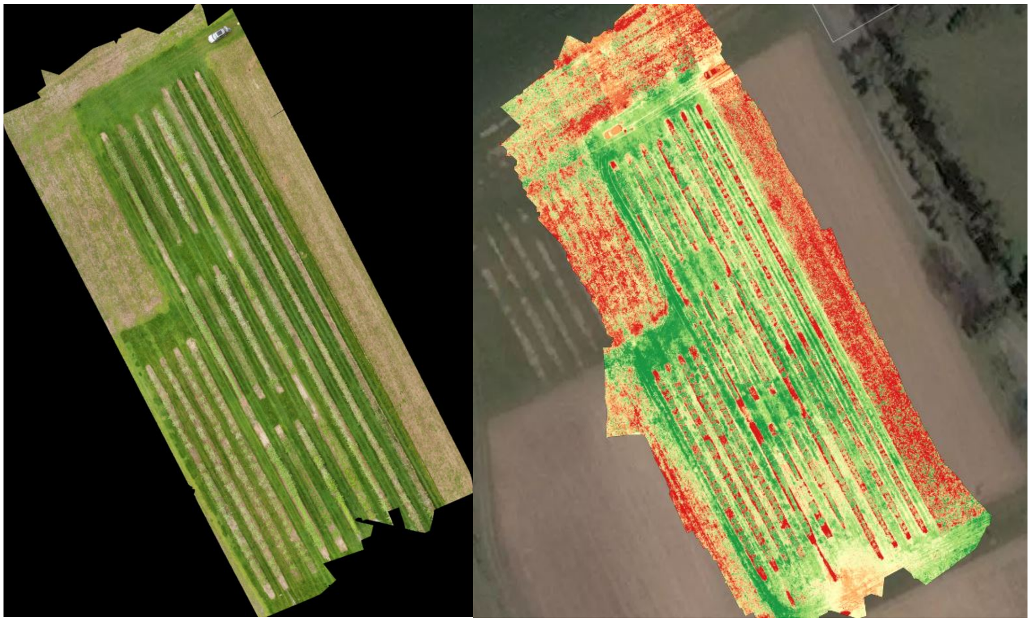

Figure 3 - RGB (left) and NDVI pseudo-color (right) orthomosaics at Rock Springs

Flight procedures:
A novel UA mission planner for close-range side-looking oblique photogrammetry of blossom canopy and crop load was developed that is terrain aware and can follow contours of hilly orchards. This is a major improvement over current mission planners that fly at a fixed altitude above the home point with the camera pointed straight down and can only see the tops of trees.

Procedures (Year 3):
Manufacturing firms typically use database driven management software to organize and analyze data on productivity of their manufacturing processes. Unfortunately agriculture has not been able to adopt many of these methods.

Specifically, this proposal will explore industrial management concepts to monitor productivity of individual trees in orchards as if they were machine tools in a factory. Input data from UA (GPS location for trees, blossom canopy coverage) and manual input data (pruning, spraying, weather) will be entered into an orchard management database throughout the year. After harvest, similar output data (fruit quality, crop load per row/block) will also be entered into the database.

The two focii of this effort will be to identify a) what data should be collected and b) how it should be organized to help growers make intelligent decisions that maximize ROI per tree. Special attention will be given to minimize data entry and maximize compatibility with commercial agricultural database software such as CropTracker from Dragonfly.

A preliminary list of hierarchical entities for a Structured Query Language (SQL) relational database is provided in Table 2.

entity	**children**	**native properties**	**derived values**
farm	orchard	GPS KML outline	spray documentation number of trees cost by date return by date
orchard	block	GPS KML outline	spray documentation number of trees cost by date return by date
block	row	purchase (date, price) GPS KML outline	spray documentation number of trees cost by date return by date
row	section	**one-time values with date** purchase (scion, root stock, vendor, cost) planting (personnel, cost) training (style, tree spacing, row spacing) GPS KML polyline **repeated values with date** spray (chemical, amount, personnel, cost) pruning/training (action, personnel, cost) irrigation (amount, personnel, cost) harvest (personnel, cost) crop load per row crop value per row	number of trees cost by date return by date
section	tree	GPS KML endpoints	number of trees cost by date return by date
tree		**one-time values with date** GPS lon/lat/alt **repeated values with date** status (alive, removed) damage (health code, insect, fungus, frost, hail, wind, personnel)	cost by date return by date

Table 1 - Database entities and parent/child relationships for orchard management

Budget for 2019

Funds to Rob Crassweller

Student summer wages and fringe benefits	$3,000.00

Fringe benefits are computed using the fixed rates of 38.97% applicable to Category I Salaries, 14.74% applicable to Category II Graduate Assistants, 7.81% applicable to Category III Salaries and Wages, 0.18% applicable to Category IV Student Wages, and 25.34% for Category V, Postdoctoral Scholars and Fellows, for fiscal year 2019 (July 1, 2018, through June 30, 2019). If this proposal is funded, the rates quoted above shall, at the time of funding, be subject to adjustment for any period subsequent to June 30, 2019, if superseding Government approved rates have been established. Fringe benefit rates are negotiated and approved by the Office of Naval Research, Penn State's cognizant federal agency.

Funds to Joe Sommer

Student programmer wages and fringe benefits	$10,000.00
MapsMadeEasy image processing services	$1,000.00
DJI Phantom 4	$2,000.00
TOTAL	**$16,000.00**