Development of a UAV-based canopy profile mapping technique to replace the mobile platform lightbar

Project No.: HORT41.Pourreza

Project Leader: **Alireza Pourreza**
Department of Biological and Agricultural Engineering, UC Davis
One Shields Ave. Davis, CA 95616
apourreza@ucdavis.edu, (530) 752-9290

Project Cooperators and Personnel:
Kyle Cheung, UC Davis
Ali Moghimi, UC Davis
German Zuniga-Ramirez, UC Davis
Bruce Lampinen, UC Davis
Kenneth Shackel, UC Davis
Gregory Browne, USDA-ARS
Brent Holtz, UCCE

Summary:
Advances in aerial robotics presents an opportunity for the development of a rapid and inexpensive method for high-resolution canopy profile mapping to adopt in precise orchard management. During this past year, aerial LiDAR point cloud data and aerial photogrammetry were collected for three research orchards and one commercial orchard. A geospatial analysis program was developed to calculate canopy cover percentage of individual trees from aerial photogrammetry data. In addition to aerial data collection, almond wet yield data was obtained at the tree level for the research orchards and will be used to develop a model of the relationship between tree canopy cover and almond yield. In initial analysis of canopy cover in Dr. Kenneth Shackel's Almond trial at the row level, Nonpareil, Wood Colony, and Monterey varieties all follow linear correlations similar to the relationship found between lightbar-measured, photosynthetically active radiation interception (%PAR) and almond yield. Further analysis on the other two research orchards will be needed to conclude if the relationship between canopy cover and almond yield at both the row level and tree level can be generalized. Additionally, the relationship between lightbar-measured %PAR and UAV-measured canopy cover percentage was inconclusive and will require further data validation and analysis.

Objective:
The primary goal is the calculation of individual canopy cover from 3D models created by aerial RGB images and photogrammetry technique and to calibrate canopy cover values by aerial LiDAR point cloud data that provides the most accurate canopy 3D reconstruction.The canopy profile information extracted from 3D models will be used to predict (potential) dry kernel yield and to compare the results with lightbar-based model for relationship between photosynthetically active radiation interception (%PAR) and almond yield. The methods developed from this goal can be used to alert growers early in the growing season to underperforming trees. The proposed solution is expected to be an alternative to the mobile platform lightbar for assessing canopy cover in almond. Specific objectives and timeline listed in Table 1.

Table 1: Main goal(s), key objectives, timelines, and milestones

<table>
<tr><th>Objective(s)</th><th>Milestone and Deliverables</th><th>Milestone Completion (*) or Expected Date (†)</th></tr>
<tr><td rowspan="4">Obj. 1: Collect aerial and ground data</td><td>Aerial Data collection (yr 1)</td><td>August 2019*</td></tr>
<tr><td>Per tree Yield measurement (yr 1)</td><td>September 2019*</td></tr>
<tr><td>Aerial Data collection (yr 2)</td><td>August 2020†</td></tr>
<tr><td>Per tree Yield measurement (yr 2)</td><td>September 2020†</td></tr>
<tr><td rowspan="6">Obj. 2: Data analytic and development of interpretation model</td><td>Data preprocessing</td><td>September 2019*</td></tr>
<tr><td>Initial comparison of lightbar to UAV imagery</td><td>December 2019*</td></tr>
<tr><td>Data processing for all data collected in 2019</td><td>March 2020†</td></tr>
<tr><td>Data preprocessing, and processing for all data collected in 2019</td><td>October 2020†</td></tr>
<tr><td>Data analytic</td><td>November 2020†</td></tr>
<tr><td>Report of yield prediction accuracy for each data collection method</td><td>December 2020†</td></tr>
</table>

Materials and Methods:

Three research orchards at the Kearney Agricultural Research and Extension Center (KARE) in Parlier, CA (Browne, Shackel, Holtz) and one commercial orchard (Clark Ranch) were used for the canopy profile mapping study. Wet yield weights were collected at harvest for all trees from the research orchards, and subsamples of harvested almonds were dried, cracked, and weighed to establish a wet yield to dry kernel yield correlation to estimate dry yield for each tree. Details of the orchard are listed in Table 2.

Table 2: Orchards used for study

Orchard	Location	Variety (Quantity)	Spacing	Yield Data?
Dr. Gregory Browne	N36.599229 W119.515579	Nonpareil (240), Lonestar (67)	6m x 3m, rectangular	Yes
Dr. Kenneth Shackel	N36.598224 W119.513250	Nonpareil (234), Wood Colony (108), Monterey (107)	6.5m x 4m, triangular	Yes
Dr. Brent Holtz	N36.59980 W119.503137	Nonpareil (91), Butte (91)	6m x 5.5m, rectangular	Yes
Clark Ranch	N36.23663 W119.46354	Nonpareil (3588), Wood Colony (4290)	22ft x 18ft (NP) 22ft x 15ft (WC)	No

Aerial LiDAR point cloud data was captured using the Phoenix LiDAR Systems Ranger+ system mounted on a DJI Matrice 600 while aerial photogrammetry was collected with a gimbal-mounted RGB camera flown on a DJI Phantom 4 Pro. PAR-interception collected by lightbar uses the same equipment described in Lampinen et al., (2012). Multiple flights were conducted between May through October 2019 to capture variation in geometry over the growing season. Dates of collection are listed in Table 3.

Table 3: Data collection dates

Orchard	LiDAR	Photogrammetry	Lightbar
Dr. Gregory Browne	6/26/19, 7/18/19	5/28/19, 6/26/19, 7/26/19, 8/7/19	6/26/19
Dr. Kenneth Shackel	6/26/19, 7/18/19	5/29/19, 6/26/19, 7/26/19, 8/7/19	6/26/19
Dr. Brent Holtz	6/26/19, 7/18/19	5/28/19, 6/26/19, 7/26/19, 8/7/19	6/26/19
Clark Ranch	6/26/19	6/26/19, 9/6/19, 10/3/19	June 2019

Aerial photogrammetry images were processed using Pix4Dmapper to create a 3-D point cloud and digital surface model (DSM). A program written in Python using open source libraries analyzed and mapped canopy profile from the DSM for individual trees.

Although multispectral and thermal aerial images were also collected, they will be analyzed in 2020 to understand the impact that spectral responses of vigor and physiology can be made to improve a yield prediction model that is based on canopy geometry. The results of this model is expected by December 2019.

Aerial photogrammetry and lightbar data have only been processed for the Shackel orchard. The remaining datasets will be processed and analyzed in 2020.

Annual Results and Discussion:

Segmentation and tree shapefiles of mature almond orchards were successfully created using the developed Python program on the photogrammetry DSM and shown in Figure 1. Shapefiles created from the program can be easily used to segment other aerial imagery datasets.

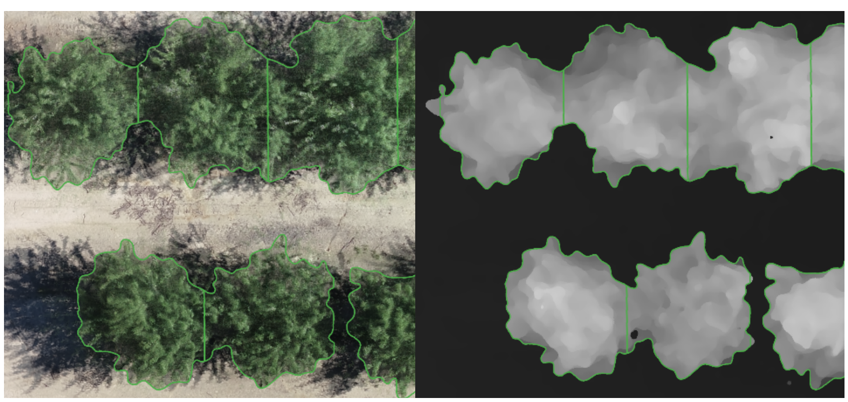

Figure 1: Segmentation of tree canopy in Shackel orchard on 6/26/19.
Left: RGB orthomosaic with tree shape overlay, Right: DSM with tree shape overlay

The segmentation method will be improved to better segment trees at the edges of orchards. These trees, with larger canopies than the rest of the orchard, have some of their leaves and branches unaccounted for in the tree shape detection. Additionally, more advanced computer vision techniques will be tested to more accurately assign pixels of a DSM to the correct tree center and provide flexibility for orchards that may not have been planted precisely.

From these shapefiles, canopy profile maps were created with examples shown in **Figure 2**. The maps show that there are both geometry variation within a row as well as between rows of the same variety. This trend can also be observed for kernel yield. The within row and row-to-row variation suggests that it may be necessary to monitor tree health on an individual basis to better detect under or overperforming trees which can be used to detect treatment application variation.

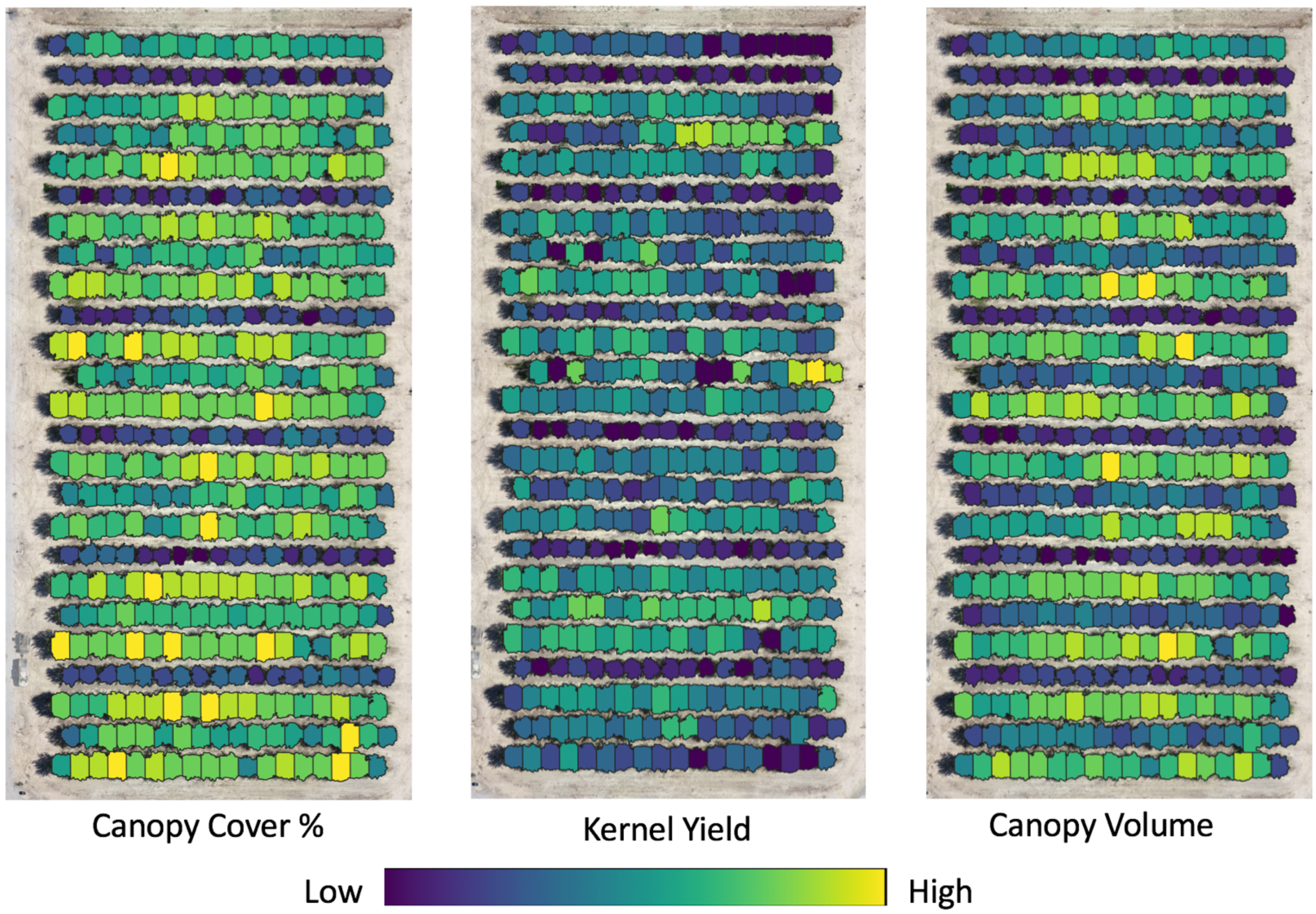

Figure 2: Canopy profile maps of Shackel orchard on 6/26/19. Varieties alternate by Nonpareil, Wood Colony, Nonpareil, and Monterey every four rows starting from the top-most row.

Comparing the relationship between canopy cover and kernel yield with %PAR and yield, there appears to be good agreement with the potential yield that Dr. Lampinen describes in previous research (**Figure 3**) both on a row average and at the tree level. This is encouraging as it may be possible to describe a potential yield relationship based on individual canopy cover. Data analyzed from the two remaining research orchards will help us to make a more generalized conclusion. Addition of spectral data and temporal data analytics will provide us with a better insight into understanding almond yield variability.

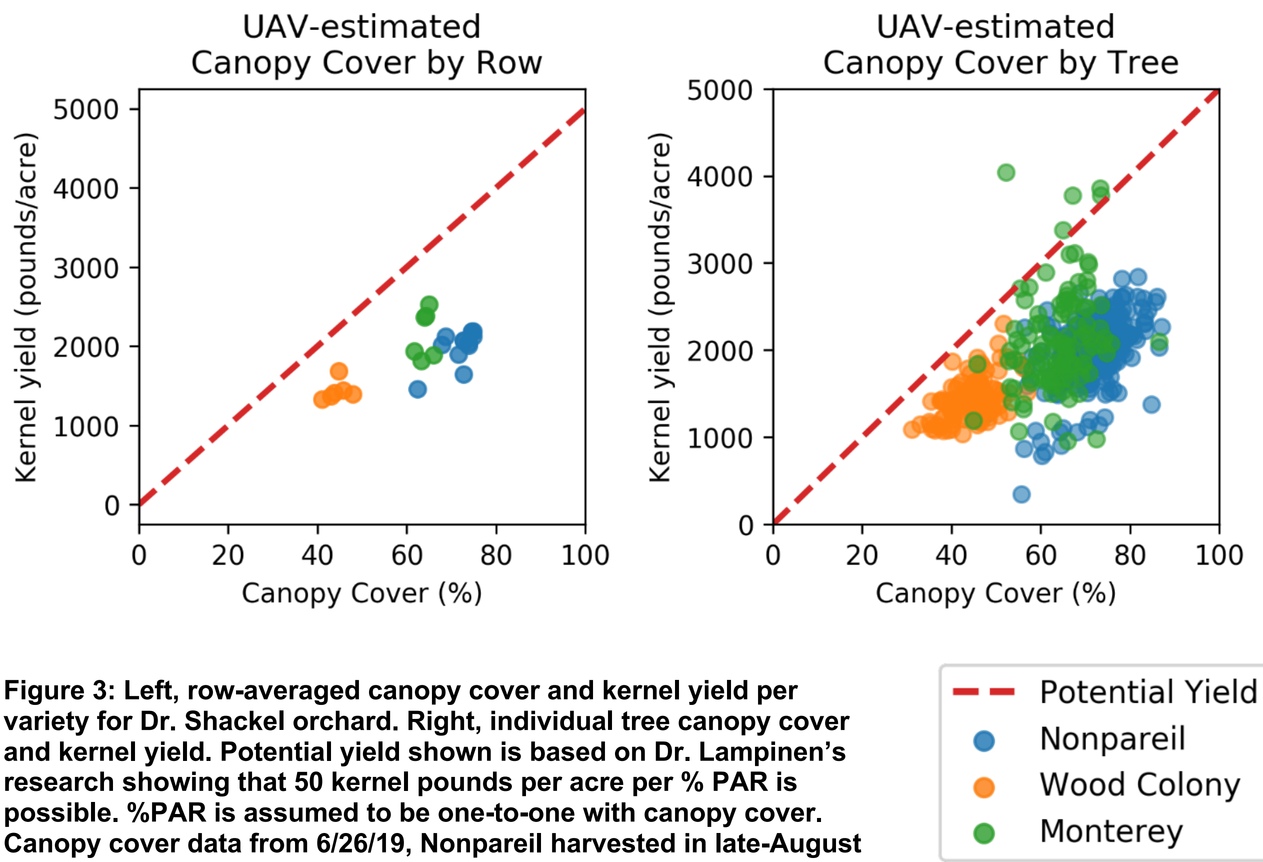

Figure 3: Left, row-averaged canopy cover and kernel yield per variety for Dr. Shackel orchard. Right, individual tree canopy cover and kernel yield. Potential yield shown is based on Dr. Lampinen's research showing that 50 kernel pounds per acre per % PAR is possible. %PAR is assumed to be one-to-one with canopy cover. Canopy cover data from 6/26/19, Nonpareil harvested in late-August 2019, Wood Colony and Monterey harvested in early-September 2019.

Linear correlation between canopy cover and yield for Dr. Shackel orchard are listed in Table 4. The reason why tree-basis correlation values for Nonpareil and Monterey are lower than the row-basis values may be again attributed to the within row variation of geometry and yield as larger variation would decrease the correlation values. The row-basis correlation value would most likely improve the yield to canopy cover correlation for Wood Colony if one of the rows was removed from the analysis (in Figure 3 left, one data point for Wood Colony is away from the dense cluster of other Wood Colony points).

Table 4: Linear correlation coefficient of canopy cover with yield

Variety	**Row-basis, Canopy Cover to Yield Linear Correlation (Pearson's *r*)**	**Tree-basis, Canopy Cover to Yield Linear Correlation (Pearson's *r*)**
Nonpareil	0.688	0.504
Wood Colony	0.273	0.496
Monterey	0.288	0.245

Both the linear regression models and correlations are not expected to generalize for all orchards as treatments and management practices differ, but the difference in row-level and tree-level models supports further investigation and data collection for a tree-level model that can better estimate yield compared to a row-level model.

Comparing by row %PAR collected by lightbar and canopy cover from UAV-measurements, there is good linear correlation between %PAR and canopy cover for Wood Colony (r = 0.337), poor correlation for Nonpareil (r < 0.01), and strongly negative correlation for Monterey (r = -0.754). The observed correlation for Nonpareil and Monterey appears to be at odds with the assumption that canopy cover and %PAR increases linearly together. Additionally, Nonpareil %PAR values appear to be lower than its canopy cover per row.

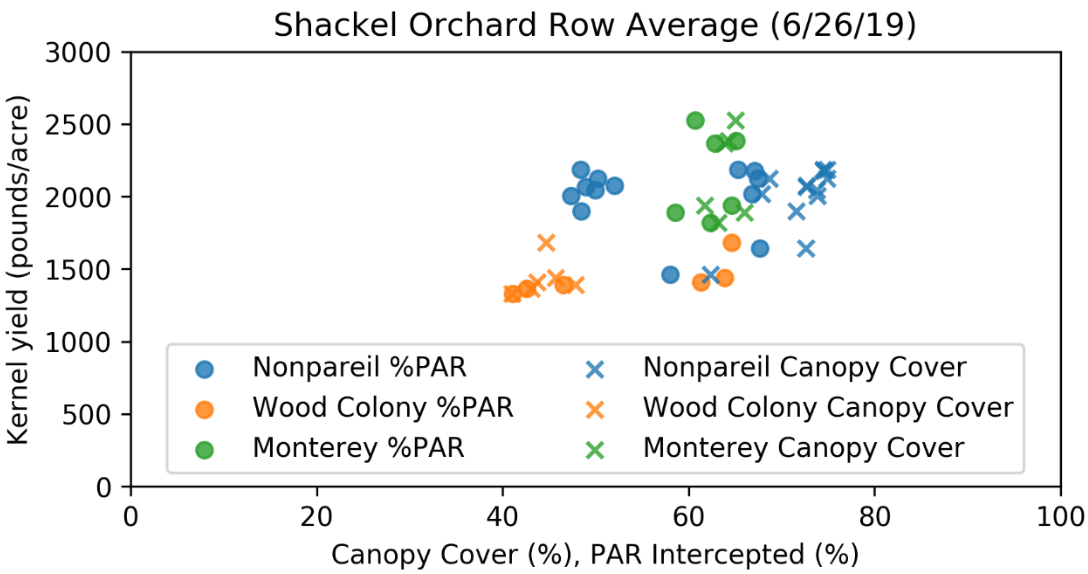

Figure 4: Row-averaged %PAR and canopy cover for Shackel orchard on 6/26/19.

One possible cause of these inconsistencies is inaccuracy of lightbar data and will require further validation. Another possible cause may be due to the estimation of canopy cover through photogrammetry which will be validated with LiDAR measurements (that provides the most accurate recistruction of canopy profile), but it is not expected that the estimates through photogrammetry will deviate significantly from LiDAR.

Outreach Activites:

Presentations:

1. Seminar: *Advanced sensing technologies and AI to develop decision-support tools for agriculture*
    a. Presenter: Kyle Cheung
    b. Date: October 2, 2019
    c. Location: UC Davis, Bainer Hall
    d. Participants: Approximately 30 with students and faculty
2. Poster at Almond Board Conference
    a. Presenter: Kyle Cheung, Ali Moghimi
    b. Date: December 10, 2019
    c. Location: Cal Expo, Sacramento, CA
3. Conference: *Calibration of photogrammetry-based canopy profile mapping using dense, sUAS-based LiDAR data in almond orchards*
    a. Presenter: Kyle Cheung

b. Date: April 27, 2020
c. Conference: Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping at SPIE Defense + Commercial Sensing
d. Focus: Accuracy and Automation in UAS Phenotyping
e. Location: Anaheim Covnention Center, Anaheim, CA

Media Interview:

1. Aerial Imaging for Crop Monitoring
    a. Outlet: VOA-TEK, produced for Voice of America News Networks
    b. Presenters: Alireza Pourreza, Ali Moghimi
    c. Date of interview: November 4, 2019
    d. Location: UC Davis

Social Media:

1. Twitter: @DigitalAg_ucd
    a. Periodic research progress updates
2. Lab Website: https://digitalag.ucdavis.edu
    a. Publicly accessible research summary with explanatory videos

Publications: None

References Cited:

Lampinen, B. D., Udompetaikul, V., Browne, G. T., Metcalf, S. G., Stewart, W. L., Contador, L., Negrón, C., & Upadhyaya, S. K. (2012). A Mobile Platform for Measuring Canopy Photosynthetically Active Radiation Interception in Orchard Systems. *HortTechnology*, *22*(2), 237–244. https://doi.org/10.21273/HORTTECH.22.2.237