Warren J. Baker Endowment
for Excellence in Project-Based Learning
Robert D. Koob Endowment *for Student Success*

FINAL REPORT

Final reports will be published on the Cal Poly Digital Commons website (http://digitalcommons.calpoly.edu).

I. Project Title

Automated Avocado Yield Forecasting Using Multi-Modal Imaging

II. Project Completion Date

September 1, 2017

III. Student(s), Department(s), and Major(s)

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(2) BioResource and Agricultural Engineering Department

(3) Electrical Engineering, BioResource and Agricultural Engineering Department

IV. Faculty Advisor and Department

Bo Liu, BioResource and Agricultural Engineering Department

V. Cooperating Industry, Agency, Non-Profit, or University Organization(s)

Mission Produce and the National Science Foundation

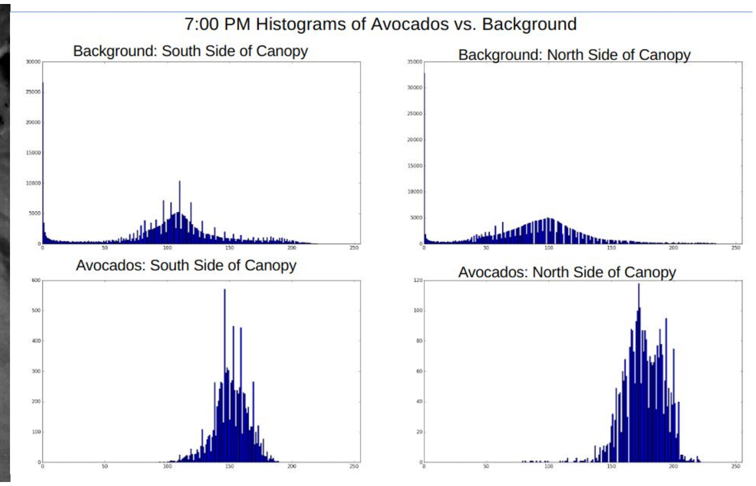
VI. Executive Summary

Yield forecasting is a common technique utilized to predict the amount of fruit expected at harvest. Orchard managers forecast yield to predict future packaging requirements, labor requirements, and to make agricultural decisions to help improve future yields. In order to forecast yield, one must first count the number of fruit on a representative sample of trees. Next, one must use a model to predict the total yield expected given the number of fruit counted. However, as population and labor costs continue to increase, a need for automation grows. While research has explored automated yield forecasting for various fruits, there currently isn't any research on automated avocado detection/forecasting.

This project explored various methods to automate avocado detection in an orchard setting using computer vision. Additionally, this project constructed a model to predict the yield of avocados at harvest when after counting the current number of avocados earlier in the year. The computer vision pipeline plans to utilizes both thermal images and visible RGB images to make an avocado classifier. However, this system has currently shows the potential of thermal-based avocado detection at various times of the day, segmenting all avocados from the background. Next, this project will continue to utilize visible RGB images to further eliminate the background.

VII. Major Accomplishments

(1) By constructing histograms and looking at various distributions, this project determined the best times to capture thermal images of avocados for segmentation. To accomplish this, an experiment was carried out as follows: First, two different avocado trees were chosen in the orchards. Then, once per hour, two images were captured per tree, one on the north side and one on the south side of each canopy. This experiment was carried out for 12 hours straight, starting from 12:30 PM to 12:30 AM. After gathering images, histograms were constructed to see how the thermal data from avocados differed from the background, noting improvements over various times and directions of image acquisition. The results from images captured at 7pm can be seen below. Although the segmentation results must improve, these images show the potential of using thermal data as extra information to identify avocados, a significant finding considering that avocados are the same color as the canopy.



(2) This project also developed a model that would allow for yield forecasting. Because a camera cannot capture the entire tree, both within and around the canopy, many avocados will be hidden from view. Therefore, a model must be used to convert the number of seen avocados to a forecasted yield. By reviewing many other methods in literature and asking a current avocado orchard manager, it was determined that the Bavendorf prediction model may be used. This model identifies a small patch on the surface of an avocado tree and counts the number of fruit seen within that patch. The number of avocados seen within that small patch is called the average fruitset density. After determining this value, one must utilize a sigmoid curve (relating yield to the canopy size) to estimate the total number avocados for that tree. Then, one may utilize previous harvest information to ultimately forecast the expected harvest weight. The image below shows how the model is used when capturing images; a square PVC frame defines the area of interest within the canopy, where the number of fruit counted within this area will determine the fruitset density. Naturally, rather than manually counting the avocados, computer vision will be used to automate this step.

(3) Finally, this project identified a method for image registration a technique used to align two different images together. This project aims to align the thermal image and corresponding visible RGB image together, allowing more advanced image processing techniques to be used for avocado identification. While image registration/alignment is often used by vision systems, image registration becomes a very challenging problem when dealing with two different sensor modalities. Firstly, each image contains different sensor sizes and lenses, causing the field of view to change. Secondly, differences in data make it difficult to automatically determine image correlations; without obvious correlations, algorithms struggle to find corresponding points across both images. Therefore, this project utilizes manual control-point selection. By manually selecting corresponding image points, image transformation becomes a much simpler problem. The results of image alignment can be seen below. Although alignment isn't perfect, this project simply needs to tweak its current methods in order to fix these deformations. Once this is completed, a whole new avenue of image processing may be utilized.

VIII. Expenditure of Funds

Unit	Price/Unit	Price
Flir Vue Pro R Thermal Camera	**$ 5000**	**$ 5000**
	Total	**$ 5000**

IX. Impact on Student Learning

The students involved in this project first learned about thermal cameras. When determining what kind of thermal camera to buy for avocado detection, it was important to understand how they worked, especially considering that thermal cameras often cost several thousand dollars. For example, one must understand the hardware interfaces necessary to obtain raw thermal data. One must understand how thermal cameras ultimately sense thermal radiation from objects and what kinds of environmental factors affect the results. Furthermore, one must understand the image processing algorithms that are used to convert 14-bit thermal data down to an 8-bit image, while also considering methods that might further enhance avocados. In essence, there was a lot to learn about thermal cameras that a first-time purchaser may not consider.

Additionally, the students involved learned about various image-processing techniques, including segmentation, feature extraction, and image alignment. Finally, students learned about the care and detail that goes into designing an experiment, especially when that experiment may influence any subsequent results or analysis. One cannot simply go out and capture thermal images. Rather, one must consider other facets of the research, such as creating a yield forecasting model, when gathering data. Furthermore, carrying out an experiment to prove, and later utilize, when one should capture thermal images of avocados was a detailed, yet significant process.