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

PROPOSAL NARRATIVE

I. Project Title
Avocado Yield-Monitoring Robot using Thermal Imaging

II. Abstract
Fruit yield estimation is an important process for efficient orchard management, allowing owners to plan for delivery and storage requirements months before the harvest. To successfully predict future yields, owners must obtain an accurate count of their current yield. However, current methods of counting fruit are time consuming and inaccurate. Therefore, this project aims to automate this process using a thermal-based computer vision system mounted on an autonomously-moving robot. Although accurate solutions involving RGB cameras exist, these solutions strongly depend on fruit color and lighting conditions. By utilizing thermal emissivity properties of fruit, fruit of any color can be extracted from the image background. To realize the benefits of a thermal-based solution, the system will be designed and tested for avocados. A segmentation algorithm will attempt to utilize features present in both the thermal and RGB images to extract the avocados from the background. Additionally, this project will combine images from different vantage points to increase fruit visibility. Finally, the solution will attempt to incorporate machine-learning techniques such as support vector machines and artificial neural networks, comparing their effectiveness to other methods, ultimately finding the most effective technique in detecting avocados.

III. Introduction
Throughout history, technology and innovation serves to improve quality of life. As new problems arise, new technologies are developed to counteract these problems. Today, new technologies oftentimes aim to improve process efficiency, a response to an exponentially-increasing world population that continues to demand resources at unforeseen rates. Therefore, engineers across the globe constantly emphasize research and development of automated systems. In particular, automated systems are currently being developed for inefficient, inaccurate, and costly agricultural processes, primarily to prevent a future where agricultural demand largely exceeds supply.

Orchards provide a significant portion of the foods people eat. Undeniably, optimizing any processes to maximize food output and decrease cost is crucial. Therefore, many technologies are being researched and developed to achieve these goals. Among these technologies include fruit harvesting systems and defective-fruit detection systems. Additionally, a significant topic of research involves fruit-yield estimation.

In orchards, obtaining accurate yield counts is crucial. Oftentimes, orchard owners obtain an early yield count of a particular fruit to predict the yield later in the year. This allows orchard owners to predict delivery and storage requirements for harvest. Naturally, an accurate count leads to more accurate yield estimations. Unfortunately, the process in which yield counts are obtained remains both time-consuming and inaccurate, often relying on a small representative sample to estimate the overall count. Instead, an autonomously-moving, yield-monitoring robot could potentially count fruit across all trees in an orchard, producing a very accurate count.

While systems currently exist to detect, and thereby count, fruit in an image, none specifically attempt to count avocados. Additionally, many existing solutions utilize RGB cameras to identify fruits. While RGB-based solutions have worked effectively for some applications, they are oftentimes susceptible to illumination effects. Additionally, RGB solutions encounter difficulties when attempting to detect green-colored fruits. On the contrary, previous works have shown thermal-based solutions to be particularly promising. A thermal-based solution stems from the unique properties of fruit emissivity; fruit generally reflects long-wave infrared radiation at a higher rate than its surrounding environment. Therefore, a thermal camera will be able to sense and reflect these differences. In light of these facts, this project will attempt to detect avocados using a thermal camera. While there currently aren't any known systems that count avocados, the research conducted on other fruit, particularly research involving thermal imaging and machine learning, provides an intriguing foundation that can be extended to avocados.

IV. Objective(s)

The project will attempt to achieve the following goals upon its completion:

1. Determine the viability of avocado detection with thermal imaging.
2. Integrate learning-based techniques such as artificial neural networks (ANN) and support vector machines (SVM) into a solution and determine the most effective approach.
3. Incorporate vision system into an autonomous ground robot designed for orchards.

V. Methodology

To complete this project, a sufficient amount of data must be obtained first. This data will be used to identify features and train the system; the larger the database, the more accurate the system can be under varying conditions. Data will be obtained in two forms: thermal and RGB. While thermal data can embolden higher-temperature fruits, RGB data can provide texture and color information, further differentiating avocados from its background. Using image fusion techniques, the thermal and RGB images can be combined together to reveal these properties.

Before fusing the thermal and RGB data together, both images will separately undergo preprocessing. With any thermal camera, the temperature data gets mapped to various colors, resulting in a thermal image. However, if the range of temperatures for avocados is known, one can adjust the temperature-mapping to a smaller range of temperatures, increasing the image contrast between the avocados and the background. On the other hand, the RGB image can undergo preprocessing to reduce the effects of lighting conditions. After this, along with additional noise reduction, both images may be fused together. Next, the avocados will be separated from the background using a threshold. Figure 1 below demonstrates preliminary results of thresholding using Otsu's method; Figure 1 also displays the ground robot that the final system will be mounted to. After thresholding, additional segmentation, followed by feature extraction and classification, will be employed. However, many methods exist to do this. For example, the image can be further segmented using a multi perceptron feedforward artificial neural network. Additionally, some methods may be used to extract features that aren't necessarily intuitive, such as the Haar-like features used in face detection. This project will explore these various methods and record the results, noting speed and accuracy.

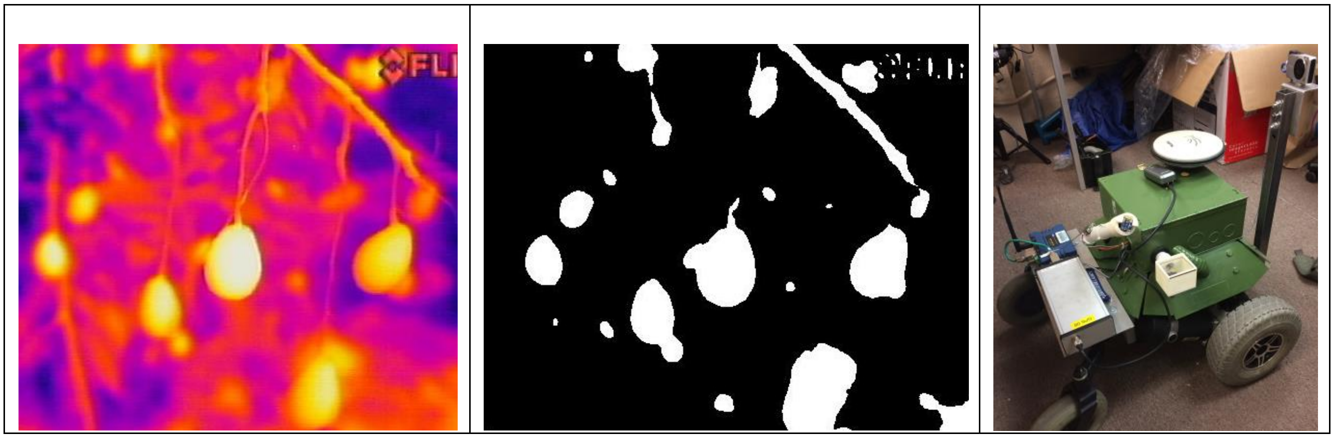
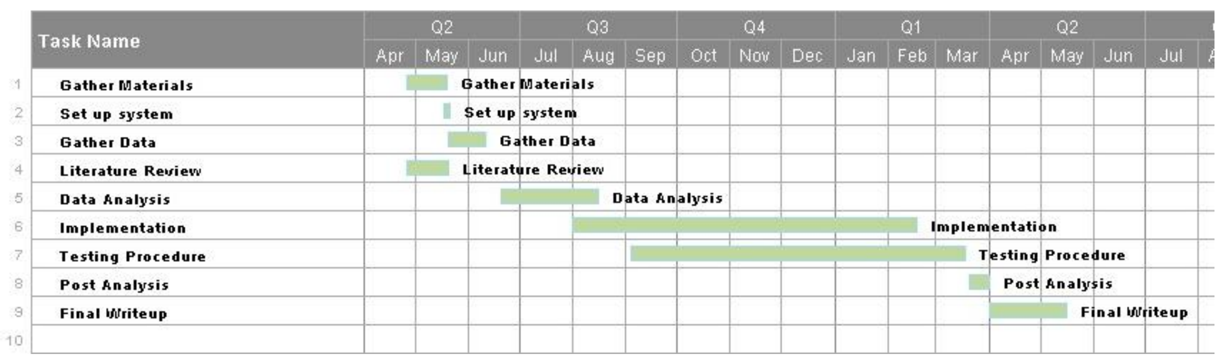


Figure 1: Results of Image Segmentation and Current Robot Implementation

Another source of difficulty will result from clustering. Therefore, the Hough Transform or other related algorithms may be used to identify clustered fruit, primarily because of their effectiveness in identifying incomplete shapes. Finally, the complete vision system will be interfaced and mounted onto the autonomous ground robot shown above, primarily implemented by the BRAE team.

It is likely that all the fruit will not be captured, even across multiple images, because the entire tree is not fully accessible from a robot. Therefore, a mathematical relationship between the number of visible fruit and the actual yield must be constructed. Constructing this mathematical model requires that sufficient data is gathered.

VI. Timeline



VII. Final Products and Dissemination

1. An autonomous, yield-monitoring robot with an avocado vision system will be developed and sent to the 2017 ASABE Conference for the student paper and poster presentation competition.
2. The final product and poster will be displayed at the Cal Poly CPE department senior project banquet.

VIII. Budget Justification

This project requests $5,000 to purchase a Tau 2 FLIR thermal camera. The camera currently available is old and often fails to produce high-contrast, fine-resolution images clearly separating the avocados from the canopy. The Tau 2 will provide better temperature resolution. Additionally, the Tau 2 has an “isotherm” feature which adjusts color mapping to a user-specified temperature range, a feature used in previous, successful works to enhance image contrast.

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CAL POLY

PROPOSAL BUDGET

Student Applicant(s): **Michael Woodson** **Charlie Ross**	
Faculty Advisor: Bo Liu	
Project Title: Avocado Yield-Monitoring Robot using Thermal Imaging	**Requested Endowment Funding**
Travel *subtotal*	**$**
Travel: In-state	$
Travel: Out-of-state	$
Travel: International	$
Operating Expenses *subtotal*	**$**
Non-computer Supplies & Materials	$
Computer Supplies & Materials	**$5,000**
Software/Software Licenses	$
Printing/Duplication	$
Postage/Shipping	$
Registration	$
Membership Dues & Subscriptions	$
Multimedia Services	$
Advertising	$
Journal Publication Costs	$
Contractual Services *subtotal*	**$**
Contracted Services	$
Equipment Rental/Lease Agreements	$
Service/Maintenance Agreements	$
TOTAL	**$5,000**

CAL POLY
SAN LUIS OBISPO
College of Agriculture, Food & Environmental Sciences
BioResource and Ag. Engineering Department

April/25/2016

Baker and Koob Endowments Office of the Provost & Executive Vice President for Academic Affairs San Luis Obispo, CA, 93407

Dear Baker and Koob Endowments Committee,

I am writing this letter to support the project - *Avocado Yield-Monitoring Robot using Thermal Imaging* at Cal Poly for financial assistance from Warren J. Baker Endowment. The team members are seeking funding opportunities to fund this innovated project.

The project members are from different departments at Cal Poly, but they all share the same interest - multidisciplinary knowledge application in real world. All the students in the team are BRAE and CPE majors, some of them have been on the Dean's list for many times. Given the quality of the students and excellent preliminary research results they already have done, I believe that they have the ability to handle this multidisciplinary project very well. The primary results of this project have been highlighted in *AGRIVIEW*, Spring 2016. That is a good proof of the quality of both the project and students. This project directly relates to Cal Poly's educational philosophy - Learn-by-Doing, exposes students to cutting edge technology in agriculture and helps students to develop critical thinking for academic research.

The Ag. Mechatronics Lab in the BRAE department will provide space, essential electrical equipment and computers for the students. I am serving as the major faculty advisor of the team, and I will provide technical guidance and support through the entire process of sensor development and final project dissemination. I will also ensure the project budget is followed and all the purchased supplies are kept in good condition, once this project is funded.

In conclusion, I am in full support of *Avocado Yield-Monitoring Robot using Thermal Imaging* research team's application. This is a very important project for both students, the

BRAE department, and even Cal Poly. Please contact me if you have any questions or would like to discuss further about this project.

Sincerely,

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