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Development of a Multispectral Sensor for Crop Canopy Temperature Measurement

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Abstract. Quantifying spatial and temporal variability in plant stress has precision agriculture applications in controlling variable rate irrigation and variable rate nutrient application. One approach to plant stress detection is crop canopy temperature measurement by the use of thermographic or radiometric methods, generally in the long wave infrared (LWIR) wavelength range. A confounding factor in LWIR canopy temperature estimation is eliminating the effect of the soil background in the image. One approach to this is time series capture of canopy temperature using single point radiometric sensors, coupled with algorithms to estimate the influence of soil on the measurement. Another approach is imaging a crop canopy using a LWIR imager paired with a visible spectrum camera covering an overlapping field, whereby canopy temperature measurements can be compiled from infrared pixels while eliminating non-crop components from the field of view using reflectance data from the visible image. In this research we developed such a multi-sensor system utilizing a miniaturized LWIR camera paired with a RGB imager. This instrument was designed to have a low enough cost to be able to deploy multiple sensors throughout a field. It is capable of automatic data logging, creating multiple data points throughout a field for the purpose of identifying variability.

Keywords. Canopy temperature, infrared, multispectral imaging, sensor development, spatial variability

Introduction

Quantifying spatial and temporal variability in plant stress has precision agriculture applications in controlling variable rate technology for irrigation and nutrient application. Crop canopy measurements are one way to capture crop stress throughout a field within a growing season. Monitoring temperature of a plant in relation to other plants or ambient temperature can then be used as a stress indicator (Tanner, 1963). A well-watered plant transpires, and evaporation cools its leaves. A water stressed plant contracts its leaf stomata, restricting transpiration, reducing energy dissipation, and raising its temperature. Canopy temperature provides an indicator of this response to stress. This correlation has been related to soil water content and used by Jackson et al. (1981) to formulate a crop water stress index that has been applied widely to irrigation scheduling (Möller et al., 2007; O'Shaughnessy et al., 2011). Plant stress of this nature can also be tied to such factors as soil depth and even leaf diseases (Lee et al., 2010).

Approaches to plant stress detection have focused on spectral reflectance indices in visible and near-infrared wavelength ranges and on crop canopy temperature measurements by the use of thermographic or radiometric methods, generally in the long wave infrared (LWIR) 8-14µm wavelength range (Bockhold et al., 2011). Sensing of canopy temperature has been widely practiced using single point radiometric sensors, such as infrared thermometers (IRT). Canopy temperature methods are useful in determining a water stress index for scheduling irrigation. To garner useful information about spatial variability throughout a field, instruments need to be deployed to capture data for significant periods of time. Sadler et al. (2002) accomplished this by mounting multiple IRT's on a center pivot irrigation system to measure crop water stress of corn and identify spatial variations. This approach utilized existing equipment to mount robust instruments to log changes in temperature. There are limitations in this approach, as the IRT's field of view includes non-crop components, such as soil, which need to be factored out using algorithms to estimate their influence on the measurement. Thus, a complete canopy is ideal in order to make the most accurate measurements of plant temperature.

Thermal imaging has been used as a way to identify spatial differences in a crop's stress. A thermal infrared camera captures electromagnetic emission of a surface, which would be critical in identifying a stressed plant (Cohen et al., 2005). Visible images capture light reflected from a surface, allowing identification of soil or leaves that are shaded within a field a view (Lee et al., 2010). By compiling these two spectral images together, it is possible to segment the regions of interest and eliminate the unwanted noise that would contribute to error in an aggregate measurement. This multispectral method is not limited by a full canopy or crop growth stage (Zia et al., 2013) and could find use throughout a growing season for corn (Mangus et al., 2016). This method has been more cumbersome than the use of IRT's, requiring more equipment and processing abilities.

Thermal imaging of a crop canopy from above requires that a sufficient altitude over the crop be attained in order to capture a wide area in a field of view. A truck crane for vineyards (Möller et al., 2007) and an unmanned aerial vehicle (UAV) in a pistachio orchard (Gonzalez-Dugo et al., 2015) have been used in response to this height requirement. Though thermal imaging has been used on agronomic crops in a greenhouse (Mangus et al., 2016), previous field-based approaches have been focused on tree and vine crops. Their discontinuous canopies and large physical size make it possible to use systems that capture a larger field of view with a lower resolution, such as 12 cm (Gonzalez-Dugo et al., 2012). These systems' high cost paired with the high resolutions required for the physical characteristics of the crop canopy has limited the use of this approach in grain crops.

Within a field, the practicalities of using thermographic and thermometric approaches to mapping variability have had limitations. Additional equipment (UAV's, cranes, etc.) is needed to allow thermal imaging of crop canopies. Infrared thermometers can be mounted on in-field equipment but are subject to noise and sampling bias. A system using miniature LWIR and visible light cameras would be a more economical approach to deploying an array of sensors similar to the way IRT's have been utilized. The individual resolution of each sensor might not be as high, but its portability and high speed sampling throughput capabilities would allow for a high resolution mapping of plant water stress throughout a field.

Objectives

The overall objectives of this project were to:

- Develop a field deployable system capable of measuring crop canopy temperature by capturing multispectral images from LWIR and visible (RGB) ranges.
- Compare the capabilities of this multispectral system to standard crop canopy temperature measurement procedures and use it to identify spatial variability in a field. A calibration procedure will be developed to focus on crop components and eliminate noise introduced by soil.
- Expand the instrument, incorporating processing techniques and additional computing power, so that it can be used on a mobile platform for wide-scale, real-time field data collection.

This paper reports on research addressing the first objective.

Imaging System Development

An electronic system capable of being deployed in a field was developed to capture multispectral images. The design of this system started with the selection of a miniature IR camera component. The Lepton LWIR (FLIR Systems, Wilsonville, OR) camera was chosen for this due to its size and resolution. The OEM availability of this imager and cost (approximately $175) allows for integration into a specialized low-cost design. The uncooled array of 80x60 pixels is sensitive to 8-14µm wavelengths and packaged with a 50° lens. It has two separate synchronous serial interfaces: one for command-control and another for video frame transmission. Each pixel's output is represented as a 16-bit value relative to the temperature of the imager's focal plane array (FPA) and does not give a direct temperature measurement. From this value, a color or monochrome gradient can be made to represent an image for display purposes.

Initial prototyping and research was done using an Arduino Due (Arduino LLC, Somerville, MA) development board powered by an ARM Cortex M3 processor. The Arduino was selected because its open source development environment allows for use of a wide array of components. The Arduino embedded C variant has a large library of open source code available that contains drivers for numerous peripherals. The visual RGB camera chosen was the ArduCAM Mini (arducam.com), a packaged 2 megapixel OV2640 sensor (OmniVision Technologies, Santa Clara, CA) with onboard image buffer and interchangeable lens. This camera is integrated into the system using freely available manufacturer's drivers. Testing a bread-boarded design allowed capture of IR and RGB images, as well as image display on an LCD. To create a robust field deployable prototype, these separate systems needed to be integrated into a single package.

An initial printed circuit board (PCB) was designed and built to incorporate the RGB and IR cameras in a package. This primary design was meant to integrate the system's main components and create room to experiment with future capabilities. This system will be able to be housed in a weatherproof package for mounting in the field. Its flow diagram is shown in Figure 1.

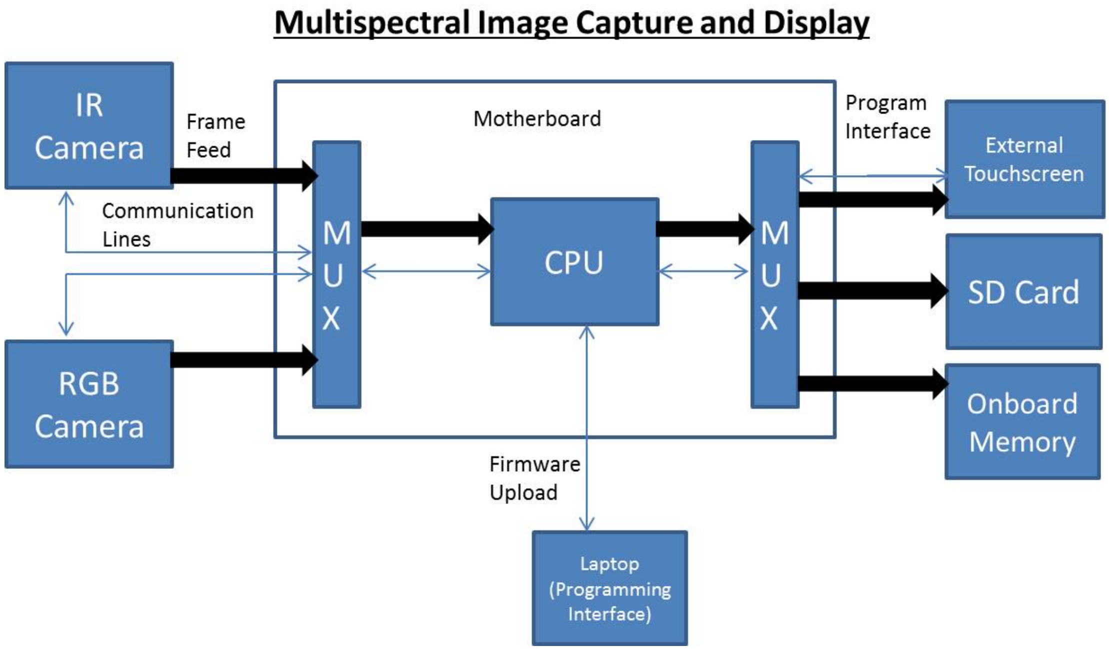
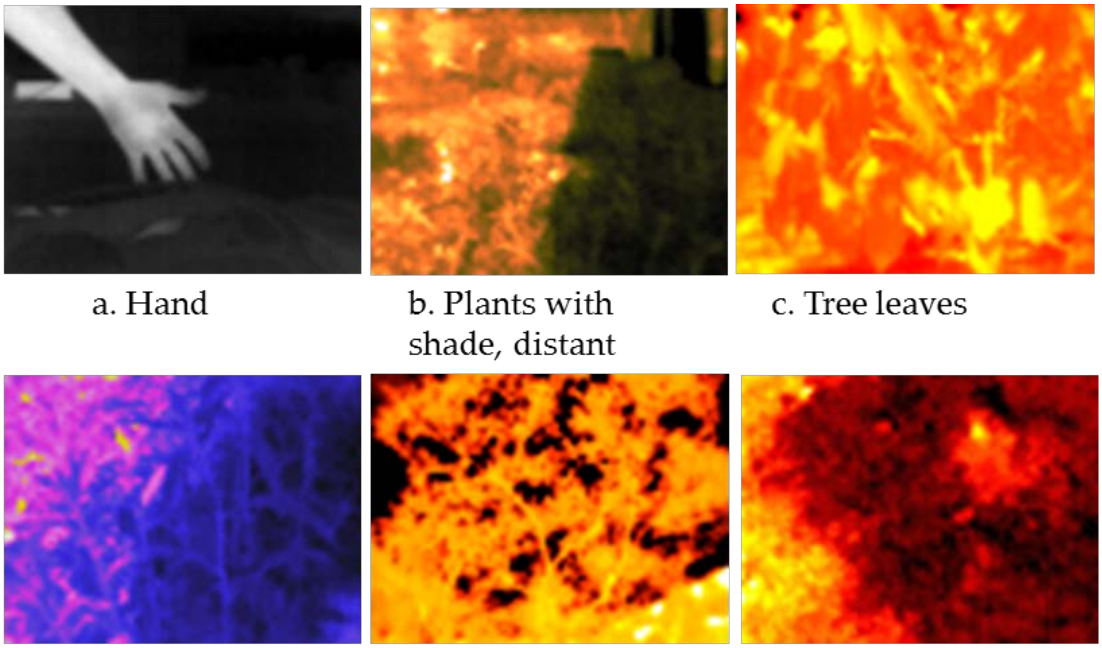


Figure 1. Block diagram displaying the major components of the multispectral imager

The central processing unit of the PCB is a Teensy USB Development Board v3.2 (PJRC.COM LLC, Sherwood, OR) that is powered by an ARM Cortex M4 processor. Its smaller package, updated architecture, and increased flexibility benefitted the overall design. The infrared camera is mounted on a breakout board that allows for direct processor to sensor communication and video streaming. The RGB imager's onboard memory stores images until the central processor can retrieve them. The PCB has additional memory that will help buffer several images for combination and processing. The touchscreen LCD allows for image display and alignment of the cameras as well as an interface to configure the system. Due to power consumption, it will only be used as a setup guide and not during deployment. There is an integrated microSD card port that will be used to store data captured in the field. For programming, troubleshooting, and direct PC communication, USB can be used with the Teensy's onboard USB capabilities.

The system's development has progressed to the point of capturing infrared images. The output can be logged on a removable SD Card. Sample images are shown in Figure 2. It is important to note that the infrared camera only outputs relative values and what is being shown is a contrast map of these values. Onboard processing can display an image using a monochrome palette as shown in Figure 2a. This image along with the image in Figure 2e show large contrasts in scene temperatures. The other scenes show the effect of shade on an image at a distance (Figure 2b) and near (Figure 2d). The image in Figure 2c shows a scene that would likely be encountered in a mature crop canopy with little temperature contrasts. The image in Figure 2f displays what would be seen in young plants, with the soil being the darker, cooler, area.



a. Hand

b. Plants with shade, distant

c. Tree leaves

d. Plants with shade at ~1m

e. Tree with sky

f. Plant on soil

Figure 2. Sample output of infrared imaging system with different color spaces applied.

Summary and Future Work

A sensor system was developed to measure crop stress through the use of infrared and visual cameras. The usefulness of a packaged multispectral imaging system relies on it being incorporated into a compact system for data logging in the field. Cameras, being the most essential part of the design, were selected based on size and cost specifications. A processor with an open source development environment was used to control the capture of image data. An electronic circuit board was designed to integrate these components into a single package. This system will allow for fixed point sampling at regular intervals while deployed in multiple locations throughout a field.

Data will be recorded over a growing season providing a way to quantify the spatial variability of stress throughout a field. Each system deployed in a field will be coupled with an IRT to highlight differences between the two approaches and serve as a validation source. Calibration procedures will be run to relate temperature to the camera's pixel output. This will require capturing images of an object at a controlled temperature, as well as recording the IR sensor's temperature, to create a table to relate raw data output to a temperature value. Further electronic development will be necessary to create an array capable of handling the high speed requirements imposed by mounting on a moving tractor. Adding secondary processing subsystem will be required to handle the processes required for moving capture and storage. To reduce the image post-processing, the central processing will provide the capability of reducing the two-dimensional data captured to a single point measurement.

Disclaimer

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or its collaborators.

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