Thermal Infrared Imaging System Usage for Crop Health Assessments

Introduction

Portable thermal infrared sensor systems have gained greater interest in the agriculture industry in the past decade. The earlier access to thermal imagery to carry out the research studies related to agricultural field work was largely from satellites. However, satellite imagery provides relatively low-resolution data (1 pixel = 100 m for Landsat-8), which is often not adequate for precision ag and phenotypic applications. But the data resolution of new compact thermal infrared sensors has greatly increased the capability of the modern-day farmer and researchers to monitor crop health, animal health and rescue, irrigation equipment monitoring, infrastructure monitoring, crop phenotyping studies, and more.

Infrared energy is a part of the electromagnetic spectrum with wavelengths larger than the visual range of the human eye (**Figure 1**). Thermal infrared sensors are responsive in the longwave infrared (LWIR) 8-14 µm domain, which record Thermal Infra-Red (TIR) radiation to display the kinetic temperature of the scene at the resolution of the sensor. TIR sensors record emitted radiation, in contrast to reflected radiation, which is recorded by multispectral remote sensors. One of the caveats in the use of TIR sensors is that most objects emit less than predicted from their kinetic temperature, and this fact is accounted for by the emissivity coefficient. However, water surfaces and vegetation, which have emissivity close to one, provide an opportunity to conduct accurate assessments of their kinetic temperature. The medium between the TIR sensor and subject, especially air temperature and humidity, can attenuate or amplify the true radiant energy. Therefore, calibration of imagery according to weather conditions is necessary to extract accurate data obtained during different measuring periods during the day.

Technology Basics

Thermal infrared sensors, which were initially developed for military applications, have evolved recently for commercial and research applications. There are two kind of thermal infrared sensors available in the market: cooled and uncooled. Cooled thermal sensors are integrated with a cryocooler. Cryocooling

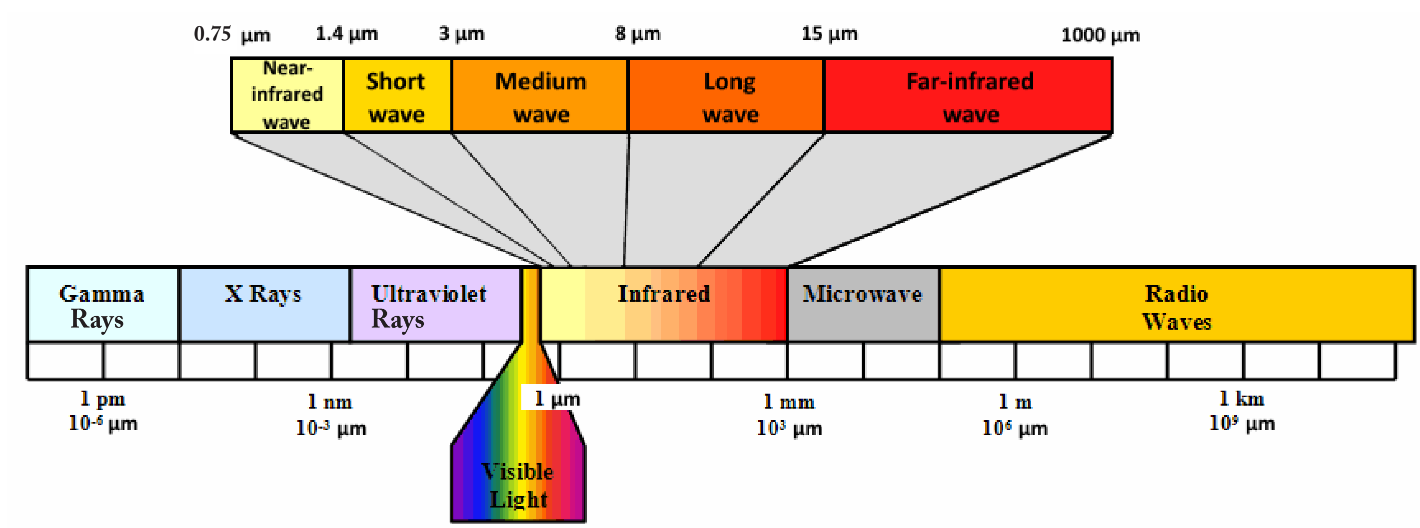

Figure 1. Electromagnetic spectrum. Thermal Infrared is part of Longwave Infrared region between 8-14 µm.
Adapted from: https://www.pro-therm.com/images/infrared_basics_figure2_large.gif

helps in reducing the noise generated by the sensor temperatures. These sensors have moving parts and use helium gas in the sensor chamber, which can escape through tiny spaces between gasket seals. Cooled thermal sensors are most sensitive to small changes in the scene temperature. But they require servicing after every 8,000 to 10,000 hours of operation. Uncooled thermal sensors don't require cryogenic cooling. These sensors are less expensive compared to the cooled sensors because they have fewer moving parts and tend to have a longer service life (**Figure 2**).

Figure 2. Uncooled thermal infrared sensor mounted on an UAV.

A commonly used uncooled thermal infrared sensor consists of a specific type of resistor called Microbolometer (**Figure 3**). It is either made from vanadium oxide (VOx) or amorphous silicon (a-Si). Changes in the object temperature cause changes in the bolometer resistance, which are then converted into electrical signals and processed into an image. Also, the lenses used in a thermal infrared sensor are made from germanium. Germanium is a good transmitter of thermal infrared energy, but it is a very expensive material. Due to this, the price for thermal infrared sensors is high.

Calibration of thermal imagery

Due to the build technology of uncooled thermal cameras, external calibration is always required, especially when absolute temperature measurement is critical for data-based decision support or modeling. External calibration helps in removing the artifacts that might arise due to atmosphere between the sensor and the observed location or due to internal working of the sensor. As we have discussed earlier, the pixel size for a thermal camera is larger than a regular camera due to its ability to capture larger wavelengths as compared to the smaller size of the visible light wavelength. Due to the large pixel size on the sensor array, a single pixel sensor is almost always susceptible to changes occurring on its surface. To tackle such issues, various methods have been tried to calibrate the thermal imagery to get accurate temperatures of the crop canopy. Numerous laboratory and field studies had been conducted in the biological and agricultural engineering department at Kansas State University to develop systems and methods for accurate calibration of TIR imagery during field applications.

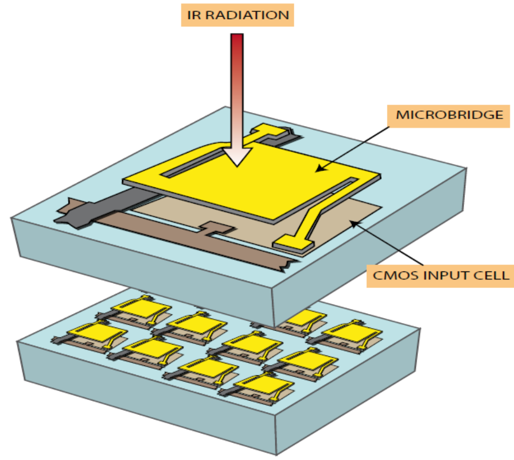

Figure 3. Schematic overview of a microbolometer detector (source: FLIR Technical Note).

The methods developed during the studies (conducted by Hatton et al., 2020; Mangus et al., 2015; Sangha et al., 2020) of localized soil moisture or canopy temperature measurements do not account for crop water stress on both a high spatial and temporal resolution for precision irrigation water management decisions and scheduling. Therefore, this study was conducted to understand the feasibility of thermal cameras in order to quantify high resolution spatial canopy temperatures in relation to soil moisture. The objectives of this study were to deploy a thermal infrared imaging system (TIRIS) that utilized a setup consisting of wooden or aluminum panels painted with matte finish black, gray, and white paints. Three 2-foot by 2-foot wooden boards were painted with all three above-mentioned colors. The aluminum sheets received a similar treatment. Additionally, a pan of 2-foot by 2-foot cross section with a depth of 2 inches was made, and inner surfaces were painted with two coats of white primer (**Figure 4,** p. 3). Later the edges were sealed with silicon and used as a water bath setup.

These reference panels were selected because they have high thermal inertia, and the same is recommended while doing in-field calibration. The low thermal inertias indicate low resistance to temperature change, resulting in a high ΔT (e.g., rocks), while the opposite is true for surfaces with high thermal inertia (e.g., water). The surfaces with a high thermal inertia (e.g., water) were most suitable to prevent temperature

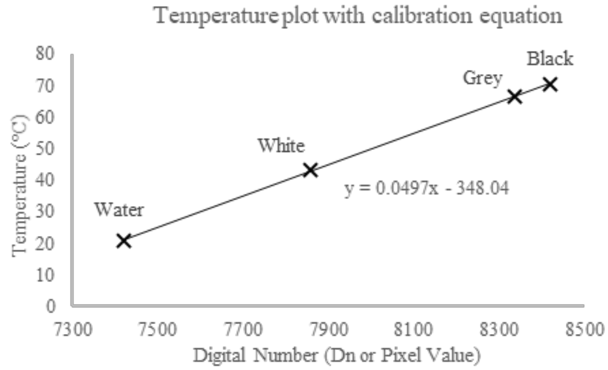

Figure 4. Thermal infrared imagery calibration setup and a sample calibration curve.

changes during even slight temporal offsets between exact overflight time and in-situ measurement time.

Things to keep in mind:

- Before flying the thermal sensor over the crops, the painted panels should be laid out and the pan filled with water on one side of the field.
- The panels and the water bath should be left in the field for at least 1 hour before the small Unoccupied Aerial Systems (sUAS) flight to bring the surfaces into equilibrium with the surroundings.
- The temperatures of the panels and the water bath could be observed using a handheld thermal gun by holding it over them 1 foot above and pointed at the center.
- Any potential shadows while taking handheld temperature of the panels should be avoided.
- The significant difference between temperature of the panels and water bath would provide a wide range of temperature for appropriate calibration.
- The appropriate time to record temperatures of reference surfaces is when the sUAS is about to pass over the panels and just after it has passed above the panels.
- These readings should later be used to calibrate thermal imagery in post processing.
- These readings are valid for a maximum flight time of 25 minutes. Flights longer than 25 minutes will require additional temperature readings from the reference panels and calibration.

Use in agricultural scenario

Commercial uncooled thermal sensors are available with different focal lengths, sensor sizes, refresh rates, etc. Selecting an appropriate sensor for the desired agricultural application is very important. Once a camera with focal length is selected, flight parameters such as flying altitude and cruising speed must be appropriately selected for collecting thermal imagery. It is necessary to evaluate which sensor will be best for the desired application, keeping in mind type of canopy cover, flying attitude, canopy height, and quality of canopy temperature.

While collecting thermal imagery using sUAS, maintaining a good flight speed is crucial. If the aircraft is flying too fast, the imagery will be blurry and out of focus. Also, if the aircraft is flying slowly, the throughput time of the thermal image collection increases. In an experiment, an sUAS was flown at speeds ranging from 2 to 5 m/s (4.47 to 11.2 mph) over a 1.6-hectare (4-acre) field at an altitude of 50 m. At speeds of 4 and 5 m/s the imagery was blurry, and the distance traveled by the time the camera sensor refreshes before taking the next image was larger. This led to poor image overlap. Due to this, many collection waypoints were missed. At a speed of 2 m/s the aircraft ran out of battery power before being able to complete the mission. An argument can be made as to why not replace the battery and fly again. Thermal energy output by the crop canopy is constantly changing. If there is a gap between collection of two sets of imagery for the same field and same day, the crop response will be greatly different.

To avoid variation due to time, it is advised to always collect thermal imagery within ± 1 hour of solar noon (time of the day when the sun is at the highest, varies from day to day) and limiting the total flying time for a single flight to a maximum of 25 minutes. Therefore, 3 m/s was found to be ideal for collecting thermal imagery.

Thermal imagery is easily affected by different environmental variables. It is crucial that thermal imagery is collected with zero to minimal cloud cover. A cloud passing over the crop field while collecting thermal imagery can cool the crop by several degrees for few seconds. This makes the section of field appear ther-

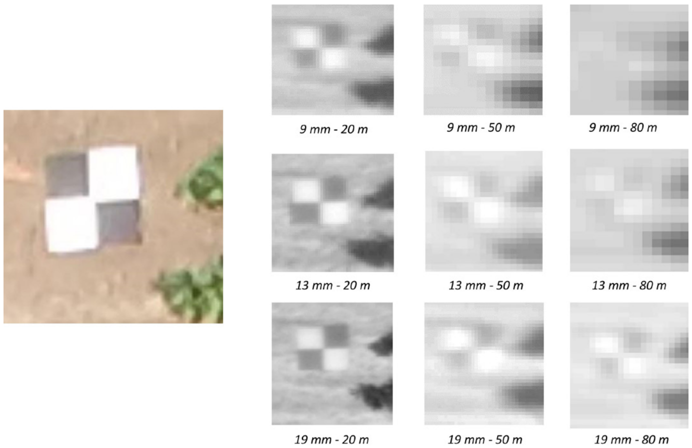

Figure 5. On the left is the ground control point from visible camera which was used to compare ground resolution for each flight combination. On the right are the segmented images from the thermal orthomosaics of the same ground control point at different resolutions.

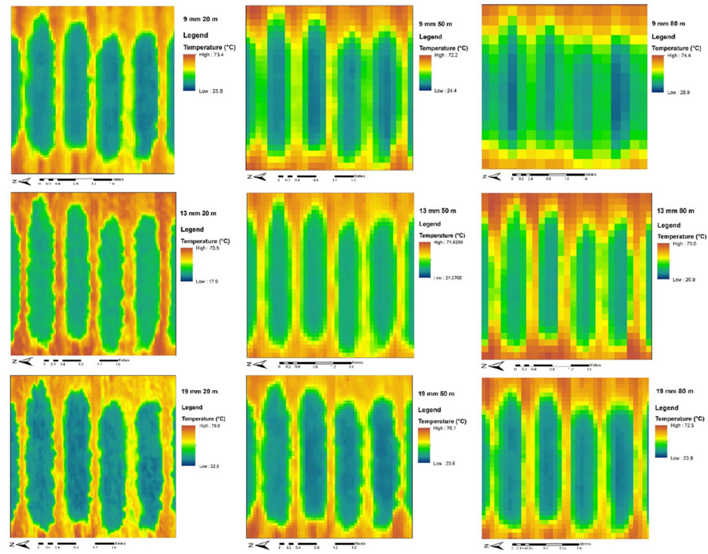

Figure 6. Thermal orthomosaics from the comparison flights.

mally cooler even if the crop is experiencing stress. While collecting thermal imagery from high altitudes such as 120 m (~ 400 ft), the environment between the thermal sensor and the crop should be accounted for. Due to the environment present between them, the thermal energy gets attenuated or magnified before reaching the sensor. This can lead to inaccurate temperature measurements of the crop canopy. This can be corrected by correctly implementing image calibration.

Depending on the size of the canopy and the size of the plant leaf, it would be important to know the extent of information present on a single pixel. If the pixel size is bigger than the canopy, then the information coming into that pixel is diluted by the background and may not accurately represent actual canopy temperature. Hence, there should be a minimum of 10 pixels on the canopy to accurately extract canopy emittance or temperature.

To evaluate this, three FLIR thermal infrared sensors with focal length 9 mm, 13 mm, and 19 mm were compared on different flight altitudes to better understand the effect of focal length and altitude on pixel size and canopy thermal imagery. The three altitudes were 20 m, 50 m and 80 m (65 ft, 164 ft and 262 ft). In **Figure 5**, plant canopy features were not distinguishable for 9 mm thermal sensor at a flying altitude of 80 m, and there is no difference between soil pixels, panel pixels, or plant pixels. On the other hand, the 19 mm thermal sensor at flying altitude of 20 m resulted in distinguishable soil, panel, and plant pixels.

This provides some idea on how the focal length and flying altitude can affect the output from the thermal imagery. Canopy temperature maps were calculated and further analyzed to evaluate the effect on the canopy temperature measured. **Figure 6** shows cropped thermal maps highlighting a 4-row soybean plot.

For the flight at an altitude of 50 m with 13 mm thermal sensor, orthomosaic showed a distinct separation between soil and canopy pixels. In the canopy region of each row there were close to 100 pixels on it that were not affected by the soil background. Results also indicated that four to five pixels were available across the width of the canopy, but these pixels were sufficient to accurately extract canopy temperature, which was not affected and diluted by the surrounding background soil. However, during the mission at 80 m with 9 mm thermal sensor the differentiation between the soil and canopy pixels is not discerned. This is due to not having a large enough number of pixels within the canopy, which potentially could result in data extraction difficulty and if not conducted correctly data may not accurately represent the true canopy temperatures.

Another major factor that is not mentioned often is geometric calibration for the imagery data. Potential of collecting thermal imagery data and analyzing it is not fully utilized until active measures can be taken using the information. For the thermal map to be compared with other data sources such as soil conductivity data or irrigation data, geo-positioning or geo-reference data is required to correctly overlay one data source over the other. Geo-referencing for thermal imagery is done by using ground control points whose accurate GPS location is known and is visible in the imagery collected. One such point is shown in **Figure 7**. The ground control points are laid in the field of interest at equal distances (max 50 m or 150 feet) such as to make a grid of points. After data collection, in post processing of the images, GPS location of ground control points are inserted to create a correctly geo-located orthomosaic.

Figure 7. Geometric correction using ground control points.

Components needed

- Unmanned aerial system (UAV)
- UAV mountable thermal sensor
- Thermal gun
- Calibration panel and water bath
- Geometric calibration setup

Summary

Thermal imagery is a great tool for crop monitoring, irrigation management, and disease detection. Many studies have shown their potential use in agricultural applications. For proper data collection using thermal imagery it is recommended to understand your sensors, carefully select flying speed, altitude, and utilize good ground calibration techniques. Following some of the information presented here could help the user to fully explore its potential.

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