Extraction of Tobacco Leaf Temperature in Complex Backgrounds Using UAV-Based Thermal Infrared Remote Sensing

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Abstract. Combining Unmanned Aerial Vehicles (UAVs) with thermal infrared remote sensing provides a rapid, low-cost, and convenient method for measuring crop canopy temperature, which can be used to infer plant water status. This study utilized UAV remote sensing to capture thermal images of tobacco plants. Through methods such as HSV color model conversion, binarization, mask overlay processing, fine background removal, and canopy contour extraction, we successfully identified and removed the mixed background of soil and mulch, accurately obtaining the canopy temperature of tobacco plants. The results showed that the average canopy temperature was 41.6±1.2℃, which was highly consistent with ground-measured temperatures (R=0.84, RMSE=0.52℃), and the canopy-air temperature difference was 8.6±1.2℃. This method is applicable for extracting canopy temperatures from infrared images of small plants or low-coverage vegetation with diverse and complex backgrounds.

Keywords: Tobacco seedlings; HSV color model; Complex background removal; Canopy contour extraction; Canopy-air temperature difference

1 Introduction

Canopy temperature of crops can be used to infer plant water stress. When soil water supply is insufficient, the plant transpiration rate decreases, and canopy temperature increases. Studies have shown that canopy temperature is highly correlated with plant water content and can serve as an indicator of water stress [1-5]. With technological advancements, the acquisition of canopy temperature has evolved from single-point measurements to UAV-based thermal camera remote sensing. Using UAV-based thermal imaging can achieve rapid and large-area data acquisition[6,7]., it has significantly improving measurement efficiency such as soybean and wheats[8-10]. However, extracting canopy temperature from small plants in complex backgrounds remains a challenge. The small plants have less information. This study focuses on tobacco seedlings and proposes a background removal and canopy temperature extraction method based on the HSV color model, verifying its effectiveness.

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2 Materials and Methods

2.1 Experimental Layout

The experimental area is located at the Fenghe Tobacco Agricultural Demonstration Base in Xundian County, Kunming City, Yunnan Province, where the "Yunyan 87" variety is planted. The experimental area is divided into 15 plots, with ridge planting and plastic film coverage. No additional irrigation was provided after the first day of transplanting.

2.2 Instruments and Materials

A DJI Matrice 300 RTK UAV and a Zenmuse XT2 thermal infrared camera (Figure 1) were used for remote sensing data acquisition. The camera consists of an RGB lens and a thermal lens. The thermal imaging camera uses a non-cooled vanadium oxide (VOx) microbolometer with a working wavelength range of 8-14 micrometers. The data format is R-JPEG* (16-bit), with an effective resolution of 640×512 pixels and a sensitivity (NETD) of ≤50 mK @ f/1.0. The RGB camera features a 1/1.7-inch CMOS sensor with an effective resolution of 20 million pixels. Both RGB and thermal infrared remote sensing images can be obtained simultaneously.

Fig. 1. DJI Matrice 300 RTK UAV (left) and DJI Zenmuse XT2 camera with twin-lens of RGB and thermal infrared (right)

2.3 Data Acquisition and Processing Workflow

Data were collected on May 19, 2023, with a flight altitude of 15 meters and an overlap rate of 80%(Figure 2). The images were stitched and geometrically corrected using DJI Terra software. Subsequently, background removal was performed through HSV color model conversion, binarization, and mask overlay, followed by extraction of the tobacco canopy temperature(Figure 3).

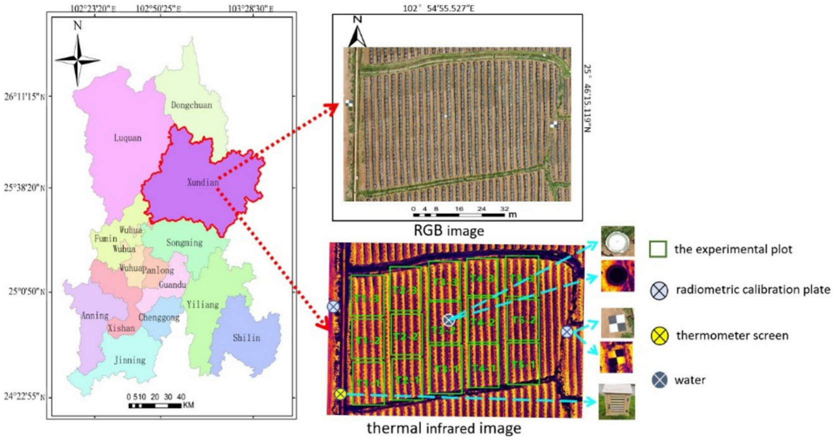


Fig. 2. Experimental area and 15 plots of RGB and thermal infrared images

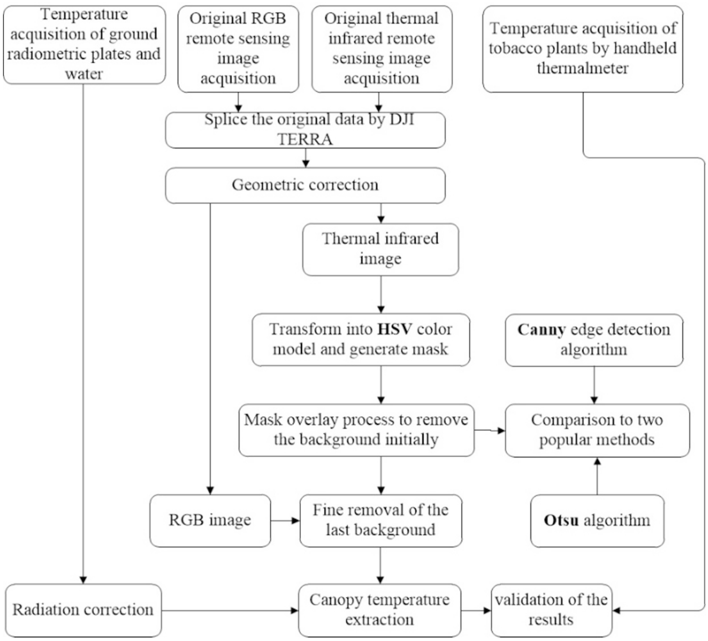


Fig. 3. Data acquisition, processing and validation process

2.4 Background Removal and Temperature Extraction

Thermal images were converted to the HSV color model using a custom program to generate masks for background removal. Compared to Canny and Otsu algorithms, this method performed well in complex backgrounds. The canopy temperature was calculated using a temperature-gray value relationship function.

2.5 Validation

The Root Mean Square Error (RMSE) effectively reflects the accuracy of the measured values. In this study, RMSE was used to validate the accuracy of tobacco plant temperatures extracted from thermal infrared remote sensing images. The formula for RMSE is:

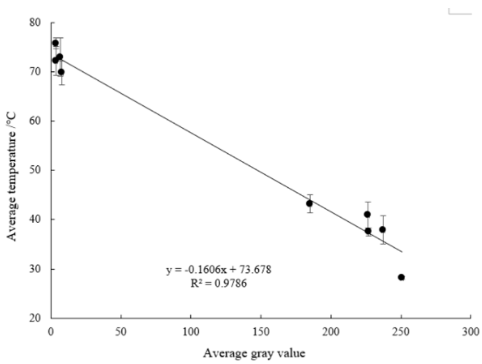
$$\mathrm{RMSE}=\left[\sum_{i=1}^{n}(T_1-T_2)^2\,/\,n\right]^{\frac{1}{2}}$$

where n is the number of ground-measured tobacco plant temperatures used for error calculation; $T1$ represents the tobacco plant temperature extracted from thermal infrared images (°C); and $T2$ represents the tobacco plant temperature measured by a handheld thermometer (°C).

3 Results

3.1 Thermal Infrared Image Radiometric Calibration

The linear correlation between the gray values of the radiometric calibration board and water temperature measured by a handheld thermometer and the gray values of the calibration objects in the thermal infrared images was analyzed (Figure 4). A linear fit yielded the temperature-gray value relationship equation: $y=-0.1565x+73.406$ ($R2=0.98$), which was used for subsequent temperature calculations.

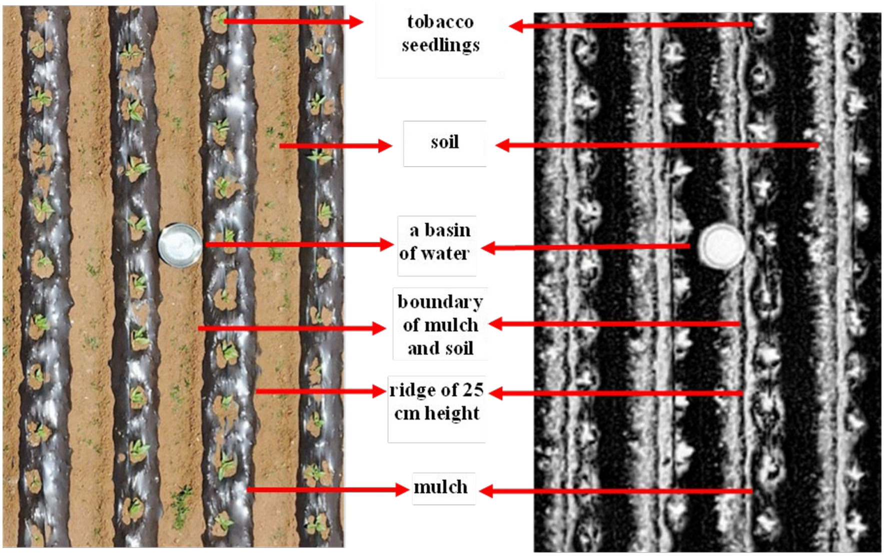


Note: Data point was mean temperature ± standard error, replication=7.

Fig. 4. relationship between average gray value and average temperature

3.2 Background Removal and Canopy Temperature Extraction

Thermal infrared images were segmented according to the experimental plots using FSCapture software. The elements of RGB images and the corresponding thermal infrared images are shown in Figure 5.



Note: In the thermal image, dark color (low gray value) indicated high temperature, light color (high gray value) indicated low temperature.

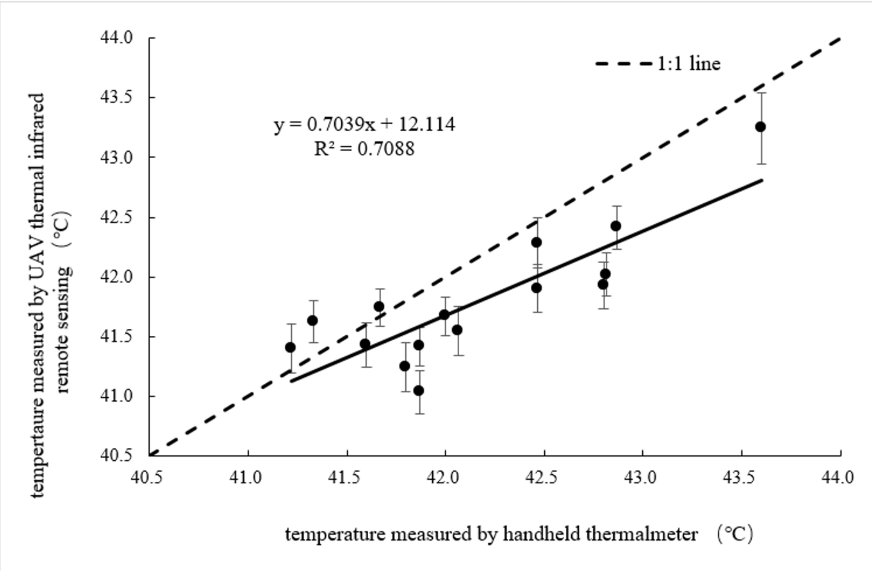
Fig. 5. Corresponding indication in a plot between RGB and thermal infrared images

The background of soil and mulch was successfully removed using the HSV color model to extract the canopy temperature of tobacco plants. Using a custom Python program called Calculate_temperature.py, the number of pixels, average gray value, and temperature of the given plants were automatically counted and calculated (Figure 6). The average canopy temperature was 41.6±1.2℃, and the canopy-air temperature difference was 8.6±1.2℃.

Fig. 6. Obtained data of each tobacco plant

3.3 Validation

The extracted tobacco plant temperatures were summarized based on the 15 experimental plots and validated using the average temperature of each plot and the ground-measured tobacco plant temperatures obtained with a handheld thermometer. The results showed that the tobacco plant temperatures extracted from thermal infrared images were highly consistent with the ground-measured values (r = 0.84) (Figure 7). The RMSE was 0.52°C, indicating that the temperatures extracted from thermal infrared images were consistent with the actual canopy temperatures of tobacco plants.



Note: Data point was mean temperature ± standard error, replication=15; the dotted line indicated the 1:1 line, and the black solid line indicated trend line.

Fig. 7. Correlation between thermal infrared remote sensing image measurement and handheld thermometer measurement

4 Discussion

The method proposed in this study performed well in complex backgrounds, outperforming Canny and Otsu algorithms, and is suitable for canopy temperature extraction of small plants. The results showed that tobacco canopy temperatures were significantly higher than air temperatures, consistent with previous studies, indicating that this method is applicable for canopy temperature monitoring under drought conditions. Ridge planting had a significant impact on background temperature, with higher temperatures on the east side than on the west side, suggesting that planting methods affect background temperatures in thermal infrared images.

However, studies have also found that the time of data collection has a significant impact on the monitoring effectiveness. In this study, due to the limitations of the flight schedule, a detailed investigation has not been carried out. When data are collected at different times, the changing temperature differences can cause backgrounds and weeds with subtle differences to easily blend in with the tobacco leaves. Of course, if an appropriate method based on plant spacing and row spacing is used for inference, these pieces of information can be removed. But if a more suitable time could be determined, such as when there is a larger temperature difference, the model could operate more effectively.

5 Conclusions

This study successfully extracted tobacco seedling canopy temperatures from UAV-based thermal infrared images using the HSV color model and radiometric calibration. The method performed well in complex backgrounds and provides a new technical means for monitoring tobacco water stress.

Acknowledgments

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