Journal of Applied Horticulture, 25(1): 39-42, 2023

DOI: https://doi.org/10.37855/jah.2023.v25i01.06

Journal of Applied Horticulture

ISSN: 0972-1045

Assessing accuracy over warm-up time of Lepton 3.5 thermal imaging for measuring leaf temperature of crops

Byungsoon Kim

Department of Computer Education, Andong National University, Andong, South Korea.
**E-mail: bsgim@anu.ac.kr*

Abstract

Accurately monitoring leaf temperatures is becoming more and more critical as more studies use a crop's leaf temperature for irrigation, disease, and pest detection. In the present study, the accuracy of a module for camera warm-up times of 30 seconds, 1 minute, 2 minutes, 3 minutes, 3.5 minutes, and 4 minutes was compared when leaf temperature was periodically measured using a Lepton 3.5 module, a low-cost thermal imaging camera. The experiment was conducted for a plant in a laboratory, and a high-accuracy LT-1T thermistor sensor was used together to compare module accuracy. The power consumption of both sensors was decreased by using the sleep mode of the module, and all measurements were conducted in intervals of five minutes. The accuracy was compared using the R-Squared, MAE, and RMSE of the two values measured by LT-1T and Lepton 3.5. As a result of the experiment, the accuracy was the highest when the warm-up time was 3.5 minutes showing the mean absolute error (MAE) and the root means squared error (RMSE) values of 0.56 °C and 0.59 °C, respectively. The accuracy was 2.5%, which was substantially higher than the 5% accuracy of the device specification.

Key words: Lepton 3.5, LT-1T, warm-up time, accuracy

Introduction

Leaf temperature is the surface temperature of a crop leaf that affects the photosynthesis and transpiration of the crop and is an important variable for determining the moisture status and health level of the crop. If the soil lacks moisture, the crop fails to transpire, causing the stomata of the crop to close and the leaf temperature to rise. Some work has utilized canopy temperature of crops to characterize stomatal conductance and closure, drought and pest stress (Su *et al.*, 2020; Yang *et al.*, 2021; Ballester *et al.*, 2013; Berger *et al.*, 2010; Chaerle *et al.*, 1999). Accurately measuring leaf temperatures during the cultivation of crops is gradually becoming more important.

Canopy temperatures of crops can be measured using thermistors, infrared thermometers, or a thermal imaging camera. Although thermistors are high-precision contact-type sensors, only one point can be measured. Accordingly, multiple thermistors are required to measure the canopy temperature of a crop. Although infrared thermometers are also accurate, the measured target must completely fill the instrument's field of view. If the background temperature is different from the object temperature, the temperature of the target cannot be accurately measured. Although the thermal imaging camera's accuracy is lower than that of previous cameras, it can measure a wide area and still measure the temperature of the target even if the background temperature is different.

Several studies have used a thermal imaging camera to measure the canopy temperature of crops. While a handheld thermal camera supports mobility, it is difficult to monitor canopy temperature periodically using it. A fixed thermal imaging camera is used for periodic measurements but is very expensive. A FLIR Lepton module is a low-cost thermal infrared imager that can be utilized like a fixed thermal camera. Su *et al.* (2020) used a handheld thermal infrared camera to measure forest canopy temperature. Luus *et al.* (2022) used a handheld thermal infrared camera to measure grapevine leaf temperature. Many studies used a handheld thermal camera to measure leaf or canopy temperatures (Su *et al.*, 2020; Stoll *et al.*, 2008; Khanal *et al.*, 2017; Baker *et al.*, 2019). Some work (Gallego *et al*, 2021; Acorsi *et al.*, 2020) utilized a Lepton 3.5 module to monitor canopy temperatures. Acorsi *et al.* (2020) reported that insufficient warm-up time before image acquisition affected the performance, and they recommended adding extra time for camera stabilization.

As each sensor has a different accuracy, if the error rate of the sensor is high, a calibration process may be required. The accuracy of Lepton 2.5 is 10%, and that of Lepton 3.5 is 5% (FLIR LEPTON Engineering Datasheet). However, there has been almost no study on the method of measuring canopy temperatures with high accuracy depending on a suitable warm-up time using a Lepton module.

This study was designed to assess the accuracy of the low-cost radiometric thermal camera FLIR Lepton 3.5 (Teledyne FLIR, Wilsonville, OR, USA) as a function of warm-up time after wake-up in the sleep mode of the module for measuring leaf temperature of crops.

This study demonstrates that when using the Lepton 3.5 module, researchers can anticipate monitoring leaf temperatures with an accuracy greater than the module specification by using an adequate warming period.

Materials and methods

Both MAE and the RMSE were used as the measures of average accuracy.

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}|x_i - y_i| \quad (1)$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2} \quad (2)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(\bar{y}_i - y_i)^2} \quad (3)$$

In these equations, N is the number of measurements, *i* index of each measurement, and x_i and y_i measured values by the LT-1T (Implexx Sense, Melbourne, Victoria, Australia) and the Lepton 3.5, respectively.

Equation (4) can be used to figure out the mean temperature of Lepton 3.5 with a 160 x 120 array (FLIR LEPTON Engineering Datasheet).

$$\text{Mean Lepton Temperature} = \frac{1}{NM}\sum^{N}\sum^{M}\frac{T_{ij} - 27315}{100} \quad (4)$$

N and M are the row and column values of the thermal image, respectively, and T_{ij} represents the target temperature of the i^{th} row and j^{th} column pixel. The result was compared to that of the highly accurate thermistor LT-1T presented in Table 1 to assess the accuracy of the Lepton module.

Table 1. Device specifications

Model	Implexx LT-1T	FLIR Lepton 3.5
Measurement method	Thermistor	Radiometric
Resolution		160 x 120 pixels
Measurement range (°C)	-5 ~ 50	High gain mode: -10 ~ +140
Accuracy	±0.08 °C	±5 °C or 5%
Field of view		57° × 71°
Spectral Range		8 ~ 14 μm
Sensitivity (°C)	0.15	0.05
Supply voltage (VDC)	5 ~ 24	1.2, 2.8, 2.5 ~ 3.1

LT-1T, a thermistor, is a subminiature touch probe that measures the temperature of a leaf. The lightweight stainless steel wire clip holds a high-precision glass-encapsulated thermistor. It has an accuracy of ±0.08 °C and a temperature range of -5 to +50 °C (Implexx Sense).

The Lepton 3.5 is a long-wave infrared camera module with radiometry. It measures the surface temperature by interpreting the intensity of the infrared signal reaching the camera. The Lepton module (FLIR LEPTON Engineering Datasheet) has an automatic shutter and a 160 x 120 pixels resolution. The radiometric accuracy of measured temperature in high gain mode is 5% over a range of -10 to +140 °C and a field of view (FOV) of 57° × 71°. The thermal sensitivity is 0.05 °C.

The prototype imager (Kim, 2021) shown in Fig. 1(a) is comprised of a Raspberry Pi 3 Model B, FLIR Lepton 3.5, and a Raspberry Pi Camera Module V2.1. A custom LoRa sensor node shown in Fig. 1(b) reads data from the LT-1T and transmits it to a gateway via LoRa.

The experiment was conducted on a 70 x 40 x 50 cm indoor plant pot shown in Fig. 2. A measurement was made every 5 minutes with the LT-1T attached to a leaf of the plant and the thermal-RGB camera installed about 30 cm above the plant. The data of the Lepton 3.5 were organized in a 160 x 120 array structure, and we designated a rectangular area on the target as shown in Fig. 3 for the leaf attached to the LT-1T, and the mean temperature value in the area was derived using Equation (4). The measurement values were stored in a MySQL and MQTT (Message Queuing Telemetry Transport) based private server and visualized using a

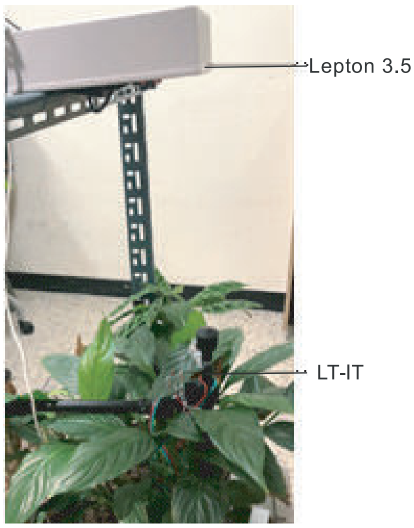

Fig. 2. Experimental setup.

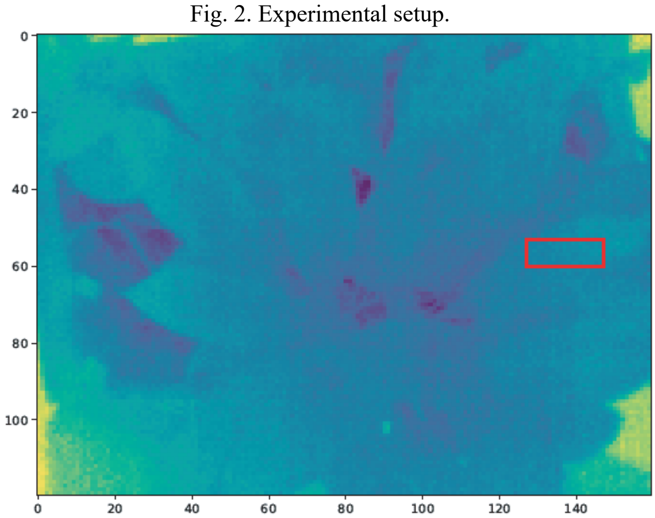

Fig. 3. Extraction temperature from a target area in a thermal image

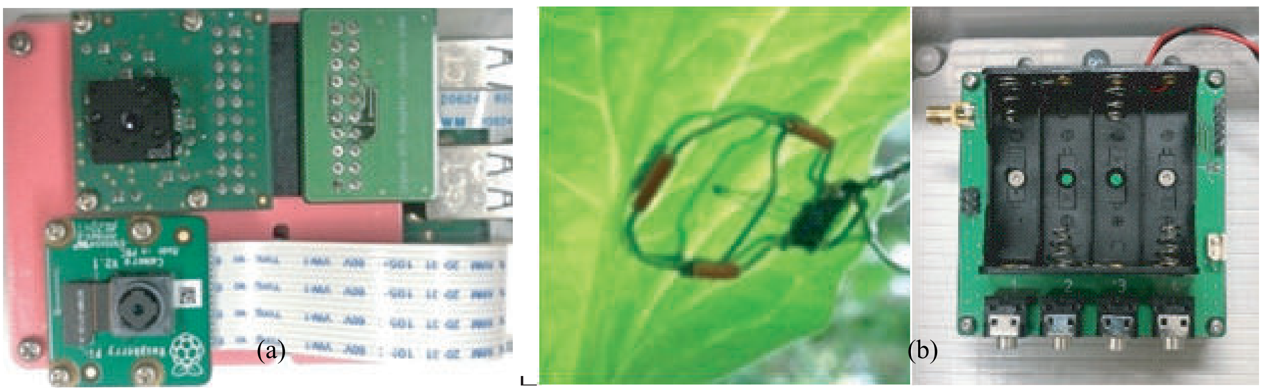

Fig. 1. Prototype: (a) thermal-RGB camera, (b) LT-1T and custom sensor node.

Fig. 4. Visualization using Grafana dashboard.

Grafana dashboard (Grafana Labs) as shown in Fig. 4.

Results and discussion

The experiment was conducted from Oct. 11 to Oct. 24, 2022, and the temperature was measured periodically while applying the sleep mode of the thermal imaging camera and changing the warm-up time.

Fig. 5 shows the variation plot for the LT-1T (solid line) and Lepton 3.5 (dotted line) sensors. The time when the temperature was the highest was between 15:00 and 16:00, and the time when it was the lowest was between 07:00 and 08:00. The points at around 18:00 on October 12 and 7:00 on October 17 showed drastic changes as the door of the laboratory was opened and the temperature of the laboratory changed drastically. When the warm-up time was 30 seconds, the values measured by the camera had a similarity of being very low showing an R-Squared value of 0.66. However, when the warm-up time was 1 minute, 2 minutes, 3 minutes, 3.5 minutes, and 4 minutes, the values measured by the camera were very similar to those of the LT-1T, all of which showed R-Squared values of 0.93 or higher. Accordingly, it can be seen that obtaining the average temperature of the designated area in the thermal image has been carried out properly.

The performance depending on the warm-up time is summarized in Table 2. Better accuracy is demonstrated by higher R2 and lower RMSE and MAE. When the warm-up time was 30 seconds, the values of MAE and RMSE were the highest, and at 3.5 minutes, the values of MAE and RMSE were the lowest. The values of MAE and RMSE gradually decreased to reach the lowest values when the warm-up time was 3.5 minutes and increased again after that. When the warm-up period was 3.5 minutes, the accuracy was 2.5%, which was significantly better than the device's accuracy of 5%, and the accuracy (°C) was 0.56°C, which was significantly better than the device's accuracy of 5°C.

Table 2. Accuracy of Lepton 3.5 depending on warm-up time

Warm-up time	Date	LT-1T mean	LT-1T standard deviation	R^2	MAE	RMSE
30 sec	2022.10.16 09:00 ~ 2022.10.17 08:00	24.18	0.54	0.66	1.32	1.36
1 min	2022.10.11 15:00 ~ 2022.10.12 19:00	22.6	0.93	0.97	1.27	1.28
2 min	2022.10.12 20:00 ~ 2022.10.14 06:00	23.0	0.79	0.98	1.12	1.12
3 min	2022.10.14 07:00 ~ 2022.10.16 08:00	23.76	0.75	0.96	0.78	0.79
3.5 min	2022.10.23 08:00 ~ 2022.10.24 08:00	23.43	0.58	0.93	0.56	0.59
4 min	2022.10.20 08:00 ~ 2022.10.21 06:00	23.49	0.74	0.94	1.21	1.23

This study focuses on accurately measuring leaf temperatures, essential for evaluating crop health. Using a low-cost Lepton 3.5 thermal camera module, we compared the impact of different warm-up times on periodic measurements. Leaf temperatures were recorded every 5 minutes in a laboratory, utilizing both the Lepton 3.5 and the high-precision Implexx Sense LT-1T thermistor. Warm-up times of 30 seconds to 4 minutes were examined, and accuracy was assessed through R-Squared, MAE, and RMSE metrics

In conclusion, the measurement values of the two sensors were very similar with the exception of when the warm-up time was 30 seconds. When the warm-up time was 3.5 minutes, the accuracy values were the highest showing MAE and RMSE values of 0.56 and 0.59, respectively and the accuracy was improved from 5 to 2.5%. In the future, the accuracy of the sensor will need to be compared to that of other non-contact sensors.

Acknowledgment

A research grant from Andong National University supported this work.

References

Acorsi, M.G., L.M. Gimenez and M. Martello, 2020. Assessing the performance of a low-cost thermal camera in proximal and aerial conditions. *Remote Sensing,* 12(21): 3591.

Baker, E.A., L.K. Lautz, J.M. McKenzie and C. Aubry-Wake, 2019. Improving the accuracy of time-lapse thermal infrared imaging for hydrologic applications. *J. Hydrology*, 571: 60–70.

Ballester, C., J. Castel, M.A. Jiménez-Bello, J.R. Castel and D.S. Intrigliolo, 2013. Thermographic measurement of canopy temperature is a useful tool for predicting water deficit effects on fruit weight in citrus trees. *Agricultural Water Mgt.,* 122: 1–6.

Berger, B., B. Parent and M. Tester, 2010. High-throughput shoot imaging to study drought responses. *J. Experimental Bot.*, 61(13): 3519–3528.

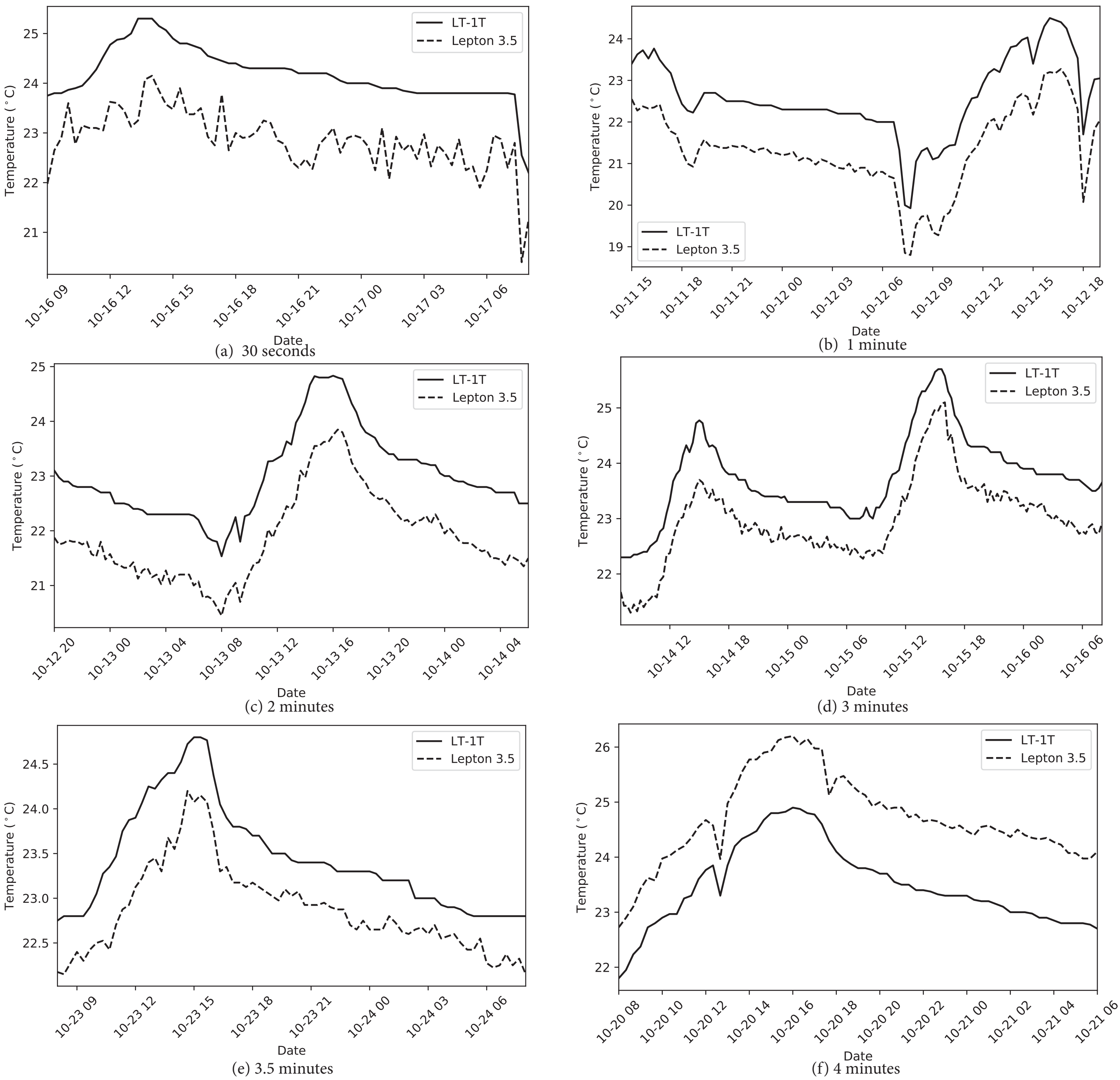

Fig. 5. Comparison of LT-1T and Lepton 3.5 according to warm-up time.

Chaerle, L., W. Van Caeneghem, E. Messens, H. Lambers and M.M. Van, 1999. Presymptomatic visualization of plant-virus interactions by thermography. *Nature Biotechnol.,* 17: 813-816.

FLIR LEPTON® Engineering Datasheet, 2022, <https://www.flir.com/globalassets/imported-assets/document/flir-lepton-engineering-datasheet.pdf>

Gallego, G.J., T.J. Gonzalez, S.F. Valles, F.J. Buendia, N.H. Hellin and T.R. Sanchez, 2021. Intelligent thermal image-based sensor for affordable measurement of crop canopy temperature. *Computers Electronics Agric.*, 188: 106319.

Grafana Labs, 2022, <https://grafana.com>

Implexx Sense, 2022, < http://implexx.io>

Khanal, S., J. Fulton and S. Shearer, 2017. An overview of current and potential applications of thermal remote sensing in precision agriculture. *Computers and Electronics in Agr.*, 139: 22–32.

Kim, B. 2021. Design and implementation of low-cost thermal-RGB camera for remote monitoring crop. *Global J. Engineering Sci.*, 8(5): 1-3.

Luus, J., D. Els and C. Poblete-Echeverria, 2022. Automatic reference temperature measurements for crop water stress index calculations: a case study on grapevines. *Computers and Electronics Agric.*, 202: 107329.

Stoll, M., H.R. Schultz, G. Baecker and B.B. Loehnertz, 2008. Early pathogen detection under different water status and the assessment of spray application in vineyards through the use of thermal imagery. *Precision Agr.,* 9: 407-417.

Su, A., J. Qi and H. Huang, 2020. Indirect Measurement of Forest Canopy Temperature by Handheld Thermal Infrared Imager through Upward Observation. *Remote Sensing*, 12(21): 3559.

Yang., M., P. Gao, P. Zhou, J. Xie, D. Han X. Sun and W. Wang, 2021. Simulating canopy temperature using a random forest model to calculate the crop water stress index of Chinese brassica. *Agron.*, 11(11): 2244.

Received: January, 2023; Revised: January, 2023; Accepted: January, 2023