The Evaluation of the Performance of Three Types of Infrared Thermometers

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ABSTRACT Many portable thermometers were used for the environmental control and management in the greenhouse. However, the information of performances included accuracy, precision and long-term stability was not mentioned in their specifications. In this study, three types of infrared thermometers were evaluated. The performance evaluation of thermometers was executed by the traced with the standard environments. The calibration equation was established by regression analysis. The results indicated the importance of the calibration work. The accuracy of these thermometers could be improved by its calibration equation. The adequate calibration equations were the high-order polynomial equations for infrared thermometers. Precision was the key factor to ensure the applicable of these thermometers. The routine calibration is the basic requirement for these thermometers.

Keywords: Infrared thermometer, Standard temperature, Calibration equation

I. Introduction

Monitoring of the physiological state for crops has become a basic technique to control the greenhouse environment and to modulate the irrigation and fertilization. The water stress may be detected by the difference between the ambient temperature and leaf temperature [10]. With the following advantages: fast response, no contact and easy to use, infrared thermometer has become a popular device to measure the leaf temperature and to evaluate the physiological state of plants [4, 7, 9, 11].

Gontia and Tiwari [8] used an infrared thermometer to measure the leaf temperature of the wheat crop. The difference between the canopy and air temperature and the vapor pressure deficit are used to calculate the crop water stress index. Blonguist Jr. et al. developed a canopy stomatal conductance model and detected the canopy temperature by an Apogee SI-111 infrared thermometer [3]. The factors affecting the accuracy of infrared thermometers were the emissivity of the canopy and the background temperature [15].

The performance evaluation of the infrared thermometer is the key to ensure the accuracy of the measurement values. Amiro et al. described the design of the leaf chambers and proposed a nonlinear calibration equation and the accuracy of measurement values of their infrared thermometer was limited within 0.2℃ [1]. Baker et al. tested the accuracy with an infrared thermometer and the measurement values of a calibrated thermocouple were served as the standard values [2]. Their results showed that the mean absolute error of this infrared thermometer was 0.04℃ as the measurement values > 24℃. Savage and Heilman selected a shortwave calibrator to test the performance of twenty-one infrared thermometers [13]. A third-order polynomial equation was proposed to express the relationship between the measurement values of

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infrared thermometers and standard values obtained from calibrator. All residual errors were within 0.15℃.

Recently, the commercial infrared thermometers become inexpensive and easy to use. It provides an opportunity to apply it in agricultural production, especially for greenhouse crops. The objectives of this study were: (1) to evaluate the performance of infrared thermocouples using the standard temperature calibrator and (2) to determine the adequate calibration equations to improve the accuracy of these thermometers.

II. Materials and methods

1. Infrared thermocouple devices

Three kinds of infrared thermocouples were used in this study. There were THI-500 and THI 700L IRT thermometer (Model THI -500 L, TASCO Japan Ltd.) and TM909A (LUTRON electronic enterprise co., Taiwan). The specifications of the manufacture are in Table 1.

2. Standard temperature

The standard temperature of the blackbody source was produced with a TC 2000 temperature calibrator (Instutek AS, Skreppestad Naringspak, Norway). The operating temperature was ranged from -40 to 150℃. The calibration certificate of the equipment indicates the 0.03℃ uncertainty. A metallic cylinder was placed in the oil bath of this calibrator. The size of this cylinder was corresponded to the requirement of the blackbody source.

3. Test procedures

The target temperature for calibration ranged from 13℃ to 37℃ with interval of 2℃. The test environment was maintained at 25℃± 1.5℃. Three replicates were made for each standard temperature. As one measurement has finished, the thermometer was taken out from the blackbody source for five minutes and then was put back for next measurement.

4. Data analysis

The performance of these infrared thermometers was assessed by their accuracy and precision.

The accuracy is expressed as the closeness with which a measurement value approached to the standard value. The error is defined as:

$$e_i = T_r - T_s \qquad (1)$$

where e_i is the errors in ℃, T_r is the reading value of the infrared thermocouple in ℃, and T_s is the standard temperature in ℃.

The smaller the e_i value, the better the accuracy of the infrared thermometer.

The regression analysis was used to establish the calibration. The criteria for selecting of the best equation are the coefficient of determination R^2, standard deviations of the estimator s and t-test. The qualitative criterion, residual plot, was used to evaluate the adequateness of calibration equations. As the data distribution of residual plots indicated a uniform pattern around the zero, the model could be recognized as the adequate model. If the residual plots showed a systematic clear pattern, the model can not be accepted.

Table 1 Specifications of the three infrared thermometers

Parameters	Tasco THI 500 and THI 700	Lutron TM909A
Measuring range	-50 to 500℃	-20℃ to 400℃
Operating temperature	0 to 50℃	0 to 50℃
Accuracy	± 1.0℃ (15-35℃)	± 1.5℃ (0℃ to 200℃)
Resolution	0.1℃	0.1℃
Field of view	11 to 1	7 to 1
Response time	0.1 sec	0.3 sec
Wavelength	5 ~ 14 μm	6 ~ 14 μm

For the classical calibration equation, the reading values of these thermometers were assumed as dependent variables and the standard values were selected as independent variables. For the inverse calibration equation, the standard values were assumed as dependent variables. The inverse calibration equation has better predictive ability and easy to be applied [5].

III. Results and discussion

1. Performance of THI 500 and THI 700 Thermometers

The relationship between the reading values of THI 500 and 700 infrared thermometers versus standard values maintained by TC-2000 calibrator is in Fig. 1. The error distribution of these thermometers is in Fig. 2. The errors were ranged from 0 to - 2.5℃ in the range between 13℃ and 37℃. It revealed the under-estimation performance. The reading values of the infrared thermocouples should not be recognized as the true values directly.

The calibration equations for this THI500 infrared thermometer in the range between 13℃ and 37℃ were:

a. linear equation

T_s = -1.3862 + 0.9660 T_r, R^2 = 0.995, s = 0.659 (2)

b. polynomial equation

T_s = 4.5526 + 0.6925 T_r + 0.006524 T_r^2, R^2 = 0.998, s = 0.431 (3)

The clean systematic pattern of residual plots was found for linear equations However, the random distribution of residual plots was found for the polynomial equation. It indicated that the polynomial equation was the adequate calibration equation for this thermometer in the range between 13℃ and 37℃. The standard deviation of these estimators for these calibration equations was 0.659 and 0.431, respectively. The accuracy of the polynomial equation was improved. The residuals plots of linear equations was liked the results of Figure 2.

The calibration equations for this THI700 infrared thermometer in the range between 13℃ and 37℃ were:

a. linear equation

T_s = 0.9559 + 0.9994 T_r, R^2 = 0.993, s = 0.4953 (4)

b. polynomial equation

T_s = 3.4491 + 0.7661 T_r + 0.004917 T_r^2, R^2 = 0.998, s=0.308 (5)

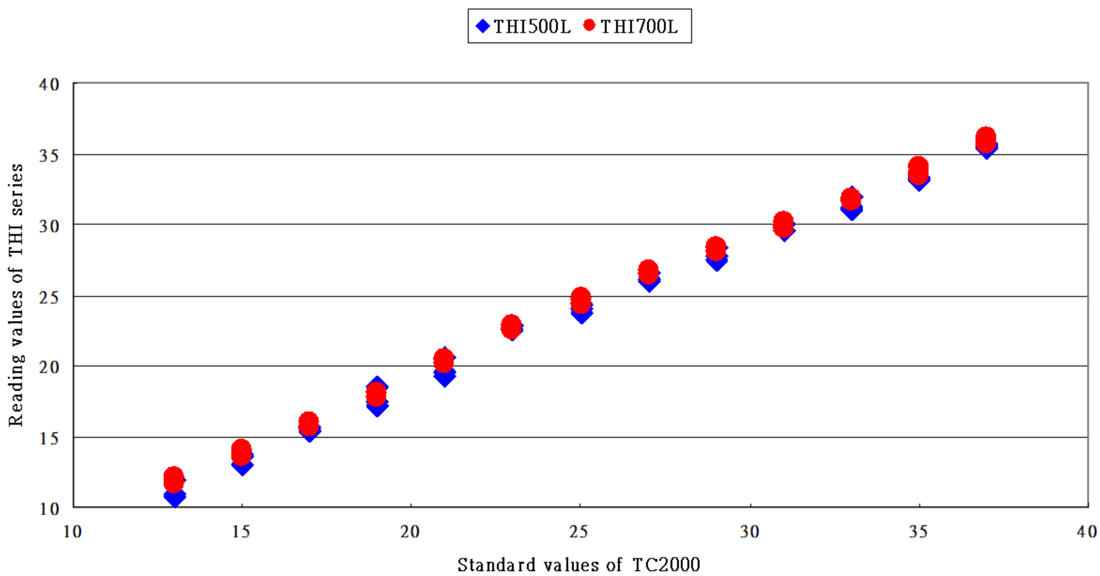

Fig. 1 The relationship between the reading values of THI 500 and 700 infrared thermometers versus standard values maintained by TC-2000 calibrator

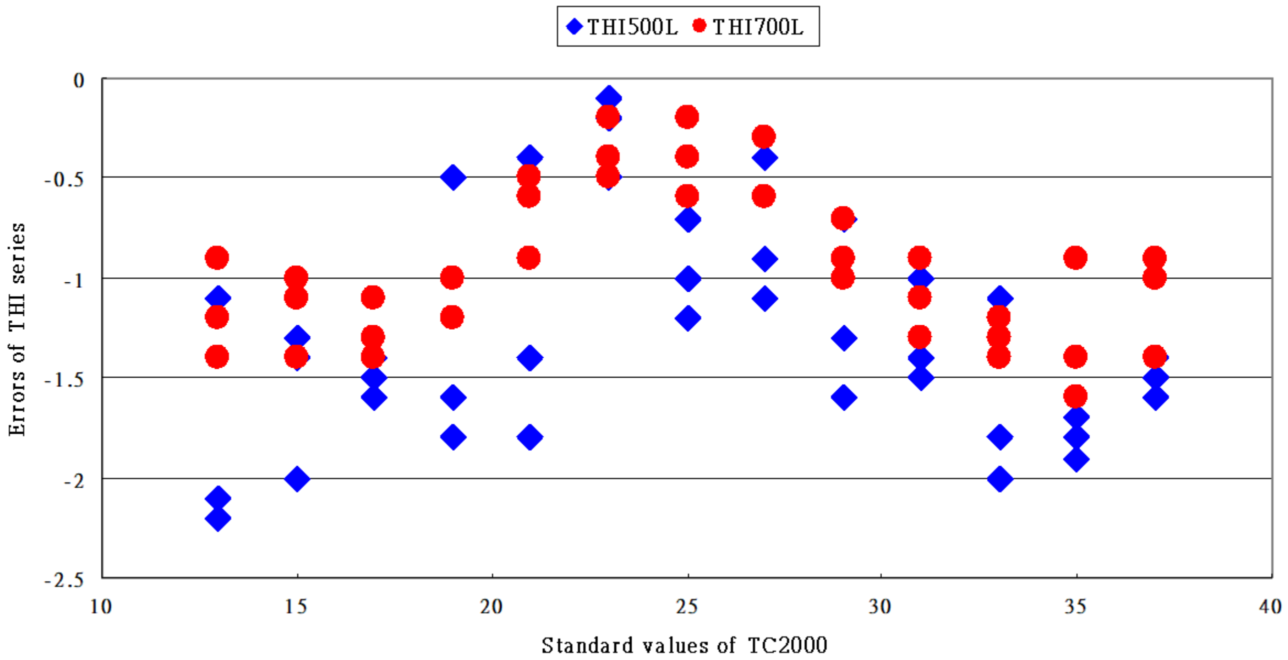

Fig. 2. The error distribution of THI 500 and 700 infrared thermometers

The calibration equations for this THI700 infrared thermometer in the range between 13℃ and 37℃ were:

a. linear equation

$T_s = 0.9559 + 0.9994\ T_r$, $R^2 = 0.993$, s = 0.4953 (4)

b. polynomial equation

$T_s = 3.4491 + 0.7661\ T_r + 0.004917\ T_r^{\,2}$, $R^2 = 0.998$, s = 0.308 (5)

The random distribution of residual plots indicated that the polynomial equation was the adequate calibration equation for this thermometer in the range between 13℃ and 37℃. The standard deviation of the estimators for two calibration equations was 0.494 and 0.308, respectively.

2. Performance of TM 909AMeters

The relationship between the reading values of TM909A infrared thermometers versus standard values maintained by TC-2000 calibrator is in Fig. 3. The error distribution of these thermometers is in Fig. 4. The errors were ranged from 0.5 to - 2.8℃ in the range between 13℃ and 22℃. It revealed the under-estimation performance. The errors were ranged from 0.5℃ to 4℃ in the range between 22℃ and 37℃. It showed the over-estimation performance. The reading values of infrared thermocouples should not be recognized as the true values directly.

The calibration equations for this TM909A infrared thermometer within the range from 13℃ to 37℃ were:

a. linear equation

$T_s = 2.8074 + 0.8475\ T_r$, $R^2 = 0.991$, s = 0.7716 (6)

b. polynomial equation

$T_s = 3.7746 + 0.7635\ T_r + 0.0041613\ T_r^{\,2}$, $R^2 = 0.993$, s = 0.414 (7)

The random distribution of residual plots indicated that the polynomial equation was the adequate calibration equation for this thermometer in the range between 13℃ and 37℃. The standard deviation of the estimators for two calibration equations was 0.772 and 0.414 respectively. The residuals plots of linear equations was liked the results of Figure 4.

The results of this study indicated that the accuracy of two types of infrared thermometers could be significantly improved using calibration equations. The error distributions were influenced by the measurement range. For the two types of thermometers, a polynomial equation was adequate for the measurement data over a 13-37℃ range. The nonlinear errors had been reported on the handbook of some manufactures [12, 14]. However, no improvement technique was mentioned in the literature. In this study, a polynomial calibration equation was established. The performance of these thermometers could be improved and the accuracy was near to 0.4℃ showed by the standard deviation of calibration equations. This performance could meet the requirement of the practical application.

In this study, the infrared thermometers were calibrated by using the standard temperature calibrator and the emissivity is assumed as 1.0. However, the emissivity of leaves of plants are ranged from 0.95 to 0.985. As the infrared thermometers were used for the determination of leaf temperature, the emissivity of thermometers need to be adjusted to ensure the accuracy of the leaf temperature measurement.

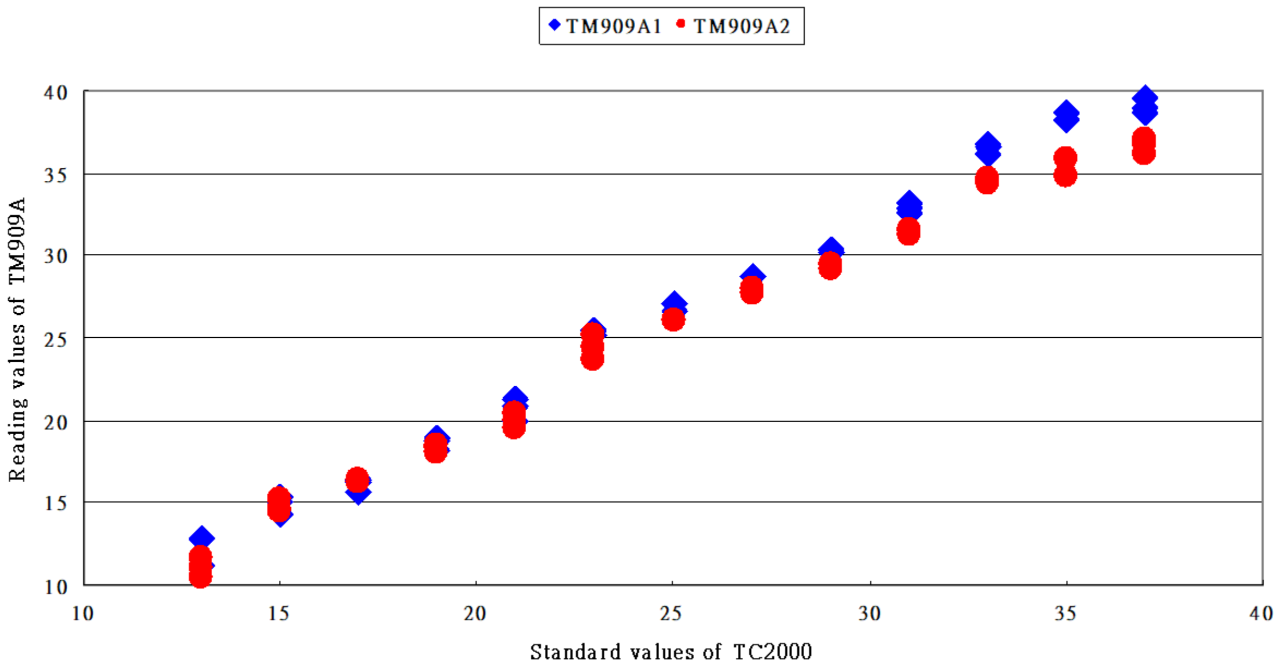

Fig. 3. The relationship between the reading values of two TM909A infrared thermometers versus standard values maintained by TC-2000 calibrator

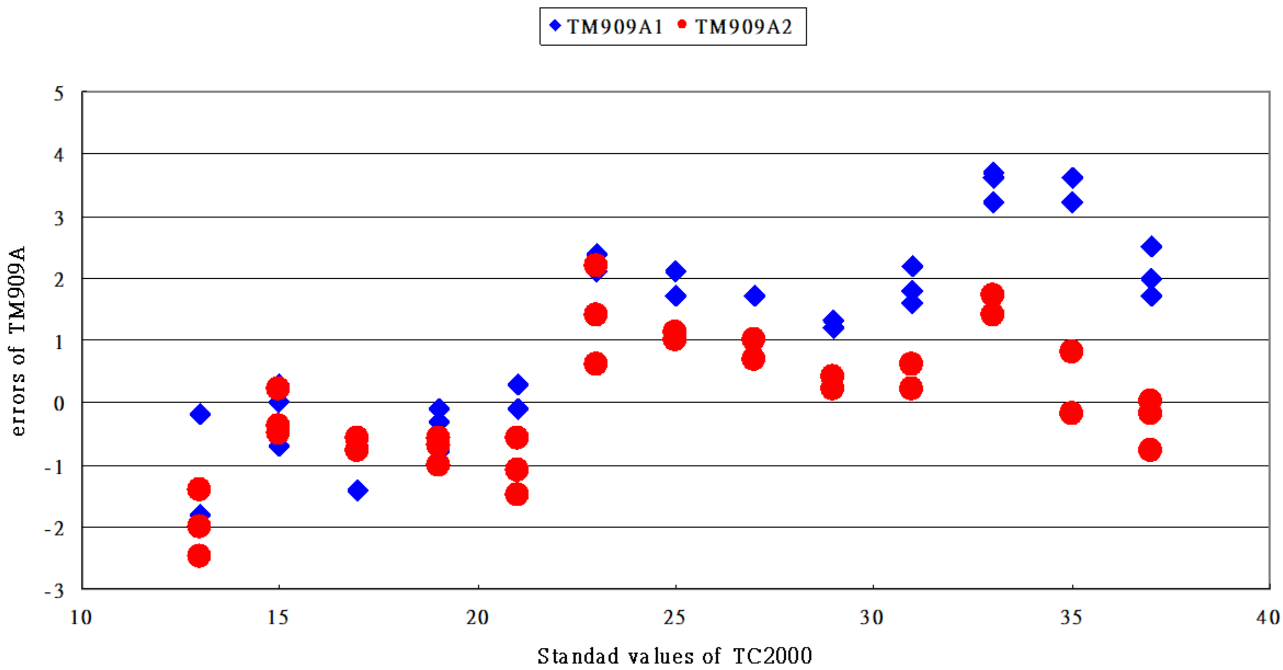

Fig. 4. The error distribution of two TM909A infrared thermometers

IV. Conclusions

In this study, the performance of three models of infrared thermometers was evaluated. The temperature maintained by the temperature calibrator and a specific blackbody source was served as the standard temperature. As the reading values of these thermometers were applied directly as true values, the errors distribution were ranged from -2.8℃ to 4℃. The accuracy of these thermometers could be improved nearly 0.4℃ by these calibration equations.

V. References

[1] Amiro, B.D., Thurtell, G.W., and Gillespie, T.J. (1983). "A small infrared thermometer for measuring leaf temperature in leaf chambers." *J. Exp. Bot.* 34:1569-1576.

[2] Baker, J.M., Noman, J.M., and Kano, A. (2001). A new approach to infrared thermometry. *Agric. Forest Meteorol.* 108:281-292.

[3] Blonquist, Jr. J.M., Norman, J.M. and Bugbee, B. (2009). Automated measurement of canopy stomal conductance based on infrared temperature. *Agric. Forest Meteorol.* 149:2183-2197.

[4] Boulard, T. and Wang, S. (2000). Greenhouse crop transpiration simulation from external climate conditions. *Agr. Forest Meteorol.* 100, 25–34.

[5] Chen, C. (2006). Evaluation of measurement uncertainty for thermometers with calibration equations. *Accred. Qual. Assur.* 11:75-82.

[6] Collatz, G.J., Ball, J.T., Grivet, C. and Berry, J.A. (1991). Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: a model that includes a laminar boundary layer. *Agric. For. Meteorol.* 54, 107–136.

[7] Ehret, D.L., Lau, A., Bittman, S., Lin, W. and Shelford, T. (2001). Automated monitoring of greenhouse crops. *Agron. Sustain. Dev.* 21, 403–414.

[8] Gontia, N.K., and Tiwari, K.N. (2008). Development of crop water stress index of wheat crop for scheduling irrigation using infrared thermometry. *Agr, Water Manag.* 95: 1144-1152.

[9] Ilahi, W.F.F. (2009). Evapotranspiration models in greenhouse. M.S. Thesis. Wageningen University, Wageningen, the Netherlands.

[10] Jones, H.G. (1999). Use of infrared thermometry for estimation of stomatal conductance as a possible aid to irrigation scheduling. *Agri. For. Meteorol.* 95, 139–149.

[11] Kumar, R., Shankar, V. and Kumar M. (2011). Modelling of crop reference evapotranspiration: a review. *Universal J. Environ. Res. Technol.* 1:239-246.

[12] OMEGA Eng. Inc. (2009). Principles of Infrared Thermocouples. www.omega.com/temperature/Z/pdf/Z076-080.pdf. OMEGA Eng. Inc., Connecticut, USA. (Accessed 29.02.2016).

[13] Savage, M.J. and Heilman, J.L. (2009). Infrared calibration of net radiometers and infrared thermometers. *Agric. Forest Meteorol.* 149:1279-1293.

[14] Schilz, J. (2001). Remote temperature measurement with PerkinElmer thermopile thermometers: A practical guide to quantitative results. PerkinElmer Optoelectronics Gmph, Wiesbaden, Germany.

[15] Yu, L., Wang, W. Zhang X. and Zheng, W. (2016). A review on leaf temperature thermometers: measurement methods and application. 3IFIP International Federation for Information Processing, Published by Springer International Publishing AG.

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