Impact of External Factors on the Accuracy of Infrared Thermographs for Measuring Elevated Body Temperature

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Abstract

Background: Infrared thermographs (IRTs) have often been used for identifying febrile individuals in public during pandemics. Standardized approaches for detecting elevated body temperature (EBT) with IRTs have been described in the ISO/TR13154 document. However, the scientific underpinnings of some aspects of this document remain unclear, as does the role of several potential confounding factors.

Objective: To investigate the effects of external factors – including environmental conditions (e.g., ambient temperature, ambient relative humidity (RH)), and deployment parameters (e.g., working distance, viewing angle, setting temperature of external temperature reference source (ETRS)) – on the accuracy of IRTs for EBT detection.

Method: Two IRTs that have been evaluated in our previous bench test [1] and clinical study [2-3] were used in this project. The influence of the ETRS setting temperature on IRT accuracy was investigated in the 30-40°C range with a calibration source (CS). The effects of viewing angle, ambient temperature, RH and working distance were evaluated through bench tests by setting the ETRS and CS temperature at 37 °C. Computer simulations were conducted to demonstrate the influence of the environmental factors on the total atmospheric transmission, total energy/radiosity received by the IRTs, and the temperature readout.

Results: ETRS setting temperature of 36°C to 37°C is optimal for EBT detection. The accuracy of the temperature measurement decreased with increasing viewing angle. The error was less than 0.05°C for viewing angle lower than 30° for both IRTs. The bench tests show differences up to 0.97°C and 0.11°C without and with ETRS respectively for RH (range 15-80%) , ambient temperature (range 18-32°C), and working distance (range 0.4-2.8 m).

For working distance, ambient temperature, and RH in the ranges of 0.2-3 m, 15-35°C, 5-95% respectively, the computer simulations show difference less than 0.30 °C and 0.04 °C without and with ETRS respectively.

Introduction

EBT is a key symptom of many infectious diseases that lead to outbreaks/epidemics/pandemics, including the COVID-19 pandemic. Screening for infectious disease based on EBT is not effective as a sole countermeasure, yet it may be a useful component of a risk management plan – particularly at the beginning of an epidemic when vaccines and testing are unavailable or limited.

Thermal modalities, including IRTs (also known as thermal/infrared cameras) and non-contact infrared thermometers (NCITs), are non-contact and noninvasive. An NCIT measures temperature at a single point using a sensor with one or a few pixels. An IRT provides a temperature map of a large area using a sensor with thousands of pixels, which enables greater flexibility to assess different regions of the face and thus improve effectiveness. **Fig. 1** illustrated the total radiosity (E_{total}, unit W·m-2) received by an IRT sensor, which can be expressed as:

$$E_{total} = \varepsilon \cdot \tau \cdot \sigma \cdot T^4 + (1-\varepsilon) \cdot \tau \cdot \sigma \cdot T_{refl}^4 + (1-\tau) \cdot \sigma \cdot T_{atm}^4$$

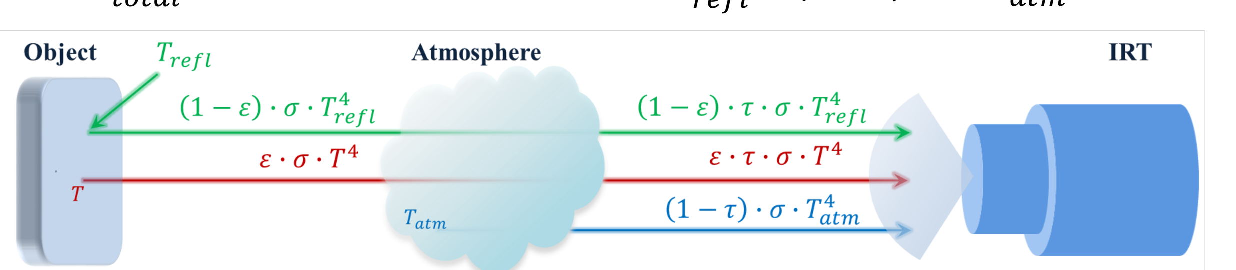

Fig. 1. Principal of the total radiation received by an IRT. [σ: Stefan-Boltzmann constant, ε: emissivity, τ: atmosphere transmittance, T_{refl}: reflected temperature, T : object temperature, T_{atm}: atmosphere temperature].

Materials and Methods

The following table lists the devices used in this study. Specifications regarding these devices can be found in our previous publication.

Device Names	Models and manufacturers	Abbreviation	Functions
IRTs	A325sc, FLIR Sys Inc	IRT-1	Measure object temperature. (320×240 pixels)
	8640 P-series, Infrared Cameras Inc	IRT-2	Measure object temperature. (640×512 pixels)
Extended area blackbodies	SR-33N-4, CI Systems Inc	ETRS	Work as an external temperature reference source (ETRS) for offset compensation, part of a **ST**.
	SR-800R-4D, CI systems Inc	CS	Serve as a calibration source (CS) or test target.
Humidifier	EE-6913, Crane-USA	-	Control RH in the range of 15-80%.
Heater	HT1188, Supply Chain Sources LLC	-	Control T_{atm} in the range of 18-32 °C.
Weather meter	Kestrel 4500NV, Weather Republic LLC	WM	Measure T_{atm} and RH, which can be used to assess τ.

Fig. 2 demonstrates the experimental setup. To Investigate the influence of the viewing angle, the CS was rotated in a wide angular range of 0-75°. To evaluate the effects of the ETRS setting temperature (T_{ETRS}), we set multiple T_{ETRS} in a broad range of 30-40°C. To assess the influence of the environmental factors, the ambient RH was changed from 15% to 85%, and T_{atm} was changed in the range of 18-32°C. The working distance was selected in the range of 0.4-2.8 m to assess the effect. Computer simulations were conducted to demonstrate the influence of the environmental factors (working distance, ambient temperature, and RH in the ranges of 0.2-3 m, 15-35°C, 5-95% respectively) on the atmosphere transmittance, total energy/radiosity received by the IRT, and the temperature readout with and without utilizing the ETRS.

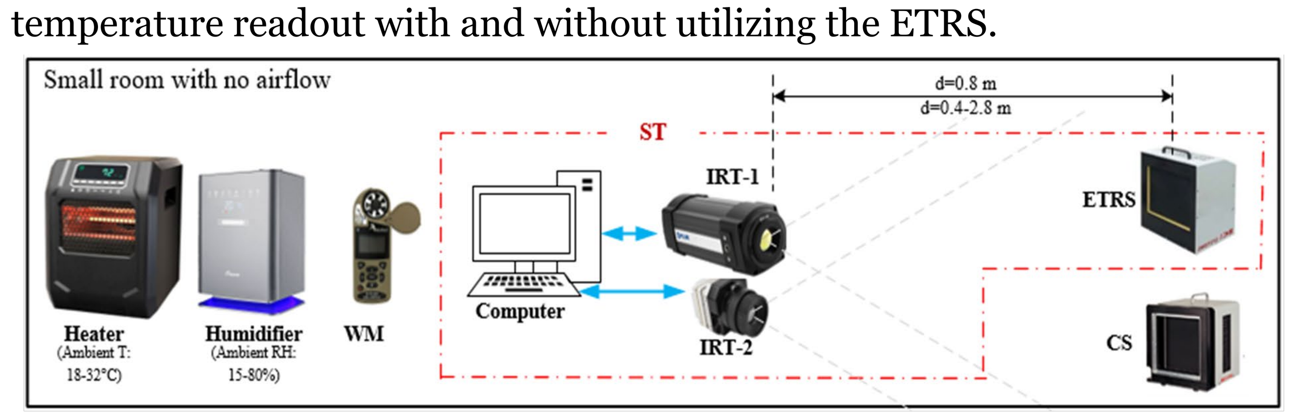

Fig. 2. The experimental setup to investigate the effects of T_{ETRS} and environmental factors. The dotted box shows the screening thermograph (ST) systems (an IRT plus an ETRS forms an ST).

Results

Figs. 3-6 respectively demonstrate the influences of viewing angle, the ETRS setting temperature (T_{ETRS}), the environmental factors (ambient RH and T) and the working distance on the two IRTs. **Fig. 7** shows the computer simulation results for the influence of the working distance and environmental factors.

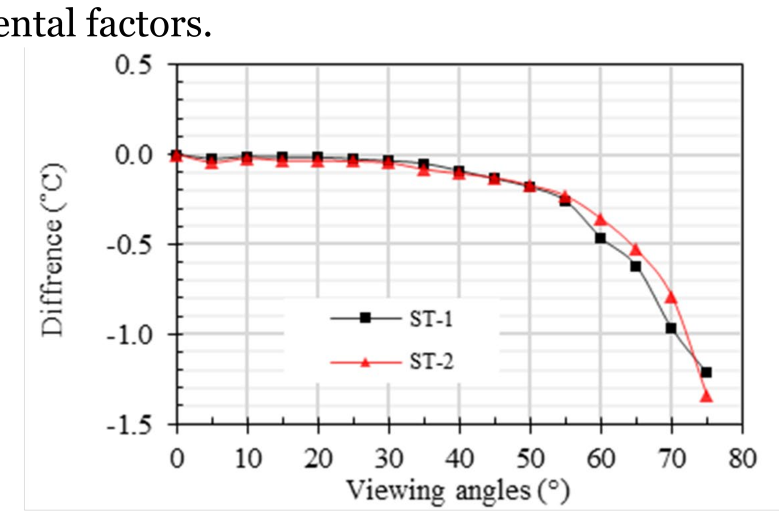

Fig. 3. The influence of viewing angle.

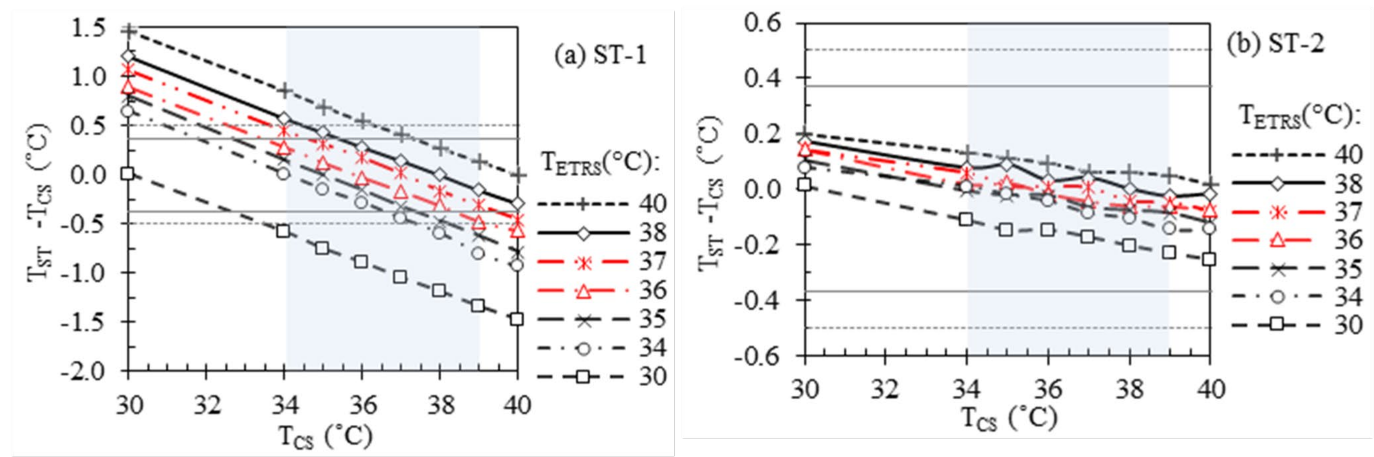

Fig. 4. Effect of temperature compensation and T_{ETRS} on ST-1 and ST-2 accuracy. Horizontal dashed lines demonstrate the area of difference between ± 0.5 °C.

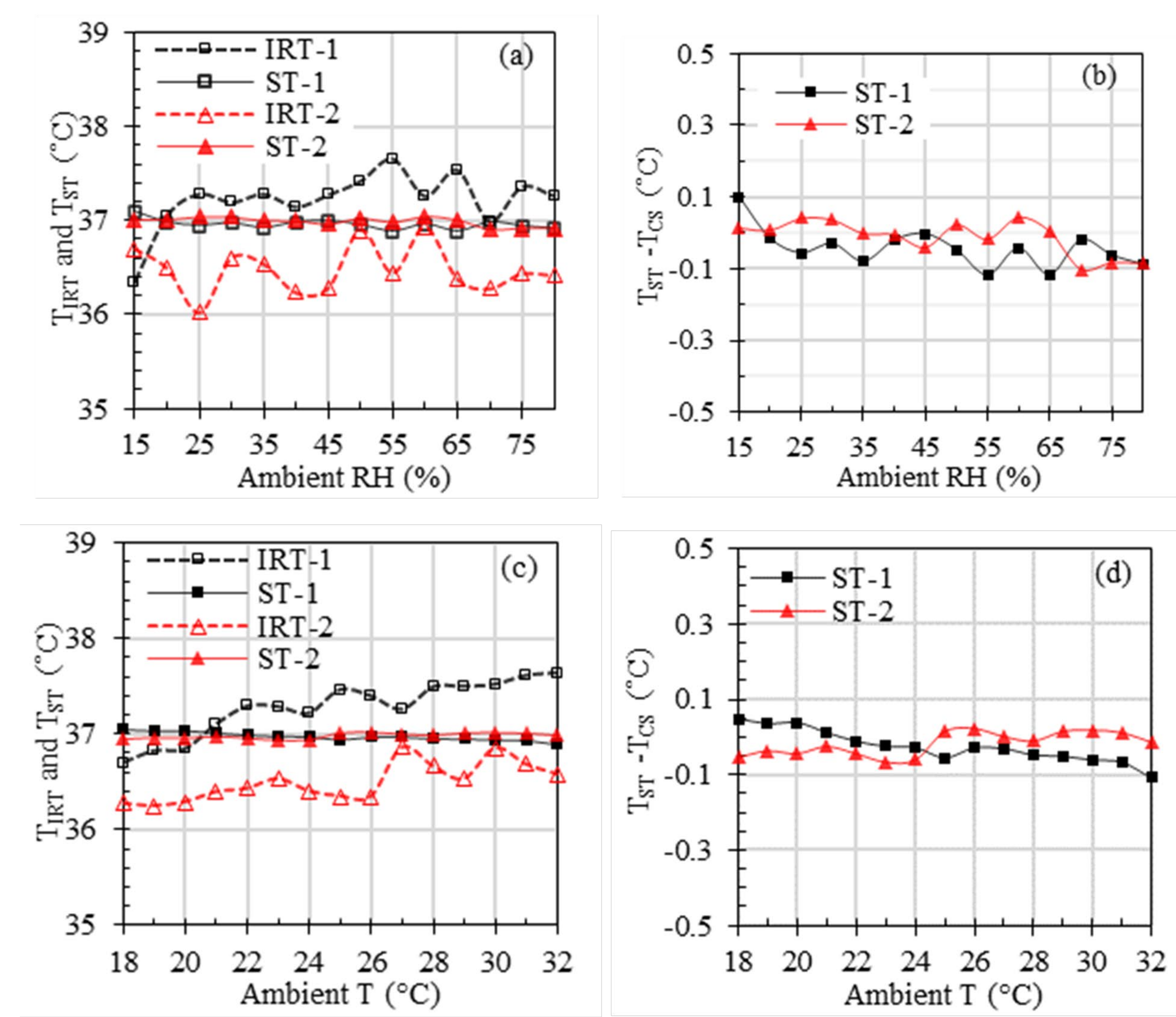

Fig. 5. Influence of the environmental factors on temperature assessment. T_{IRT}: temperature readout of an IRT. T_{ST}: T_{IRT} compensated by T_{ETRS}.
(a &b): T_{IRT}, T_{ST} and $T_{ST} - T_{CS}$ under different ambient RH with T_{atm} =24°C.
(c & d): T_{IRT}, T_{ST}, and $T_{ST} - T_{CS}$ under different T_{atm} with ambient RH of 35%.

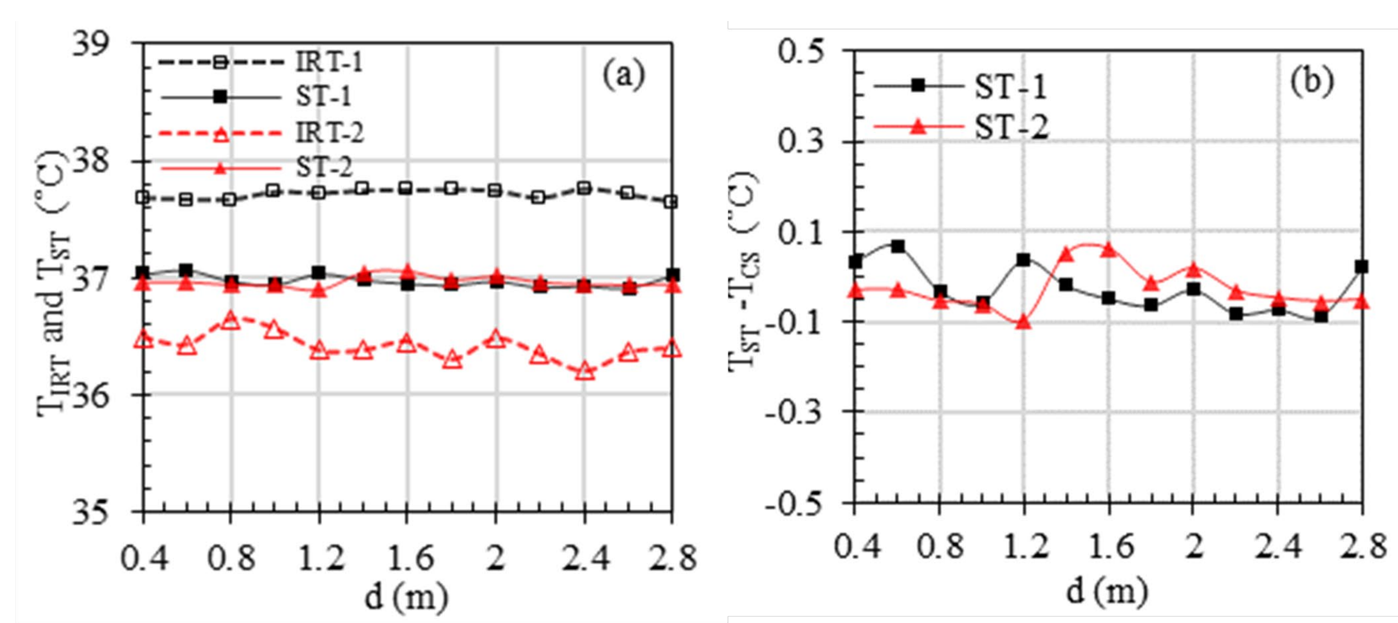

Fig. 6. The influence of working distance.

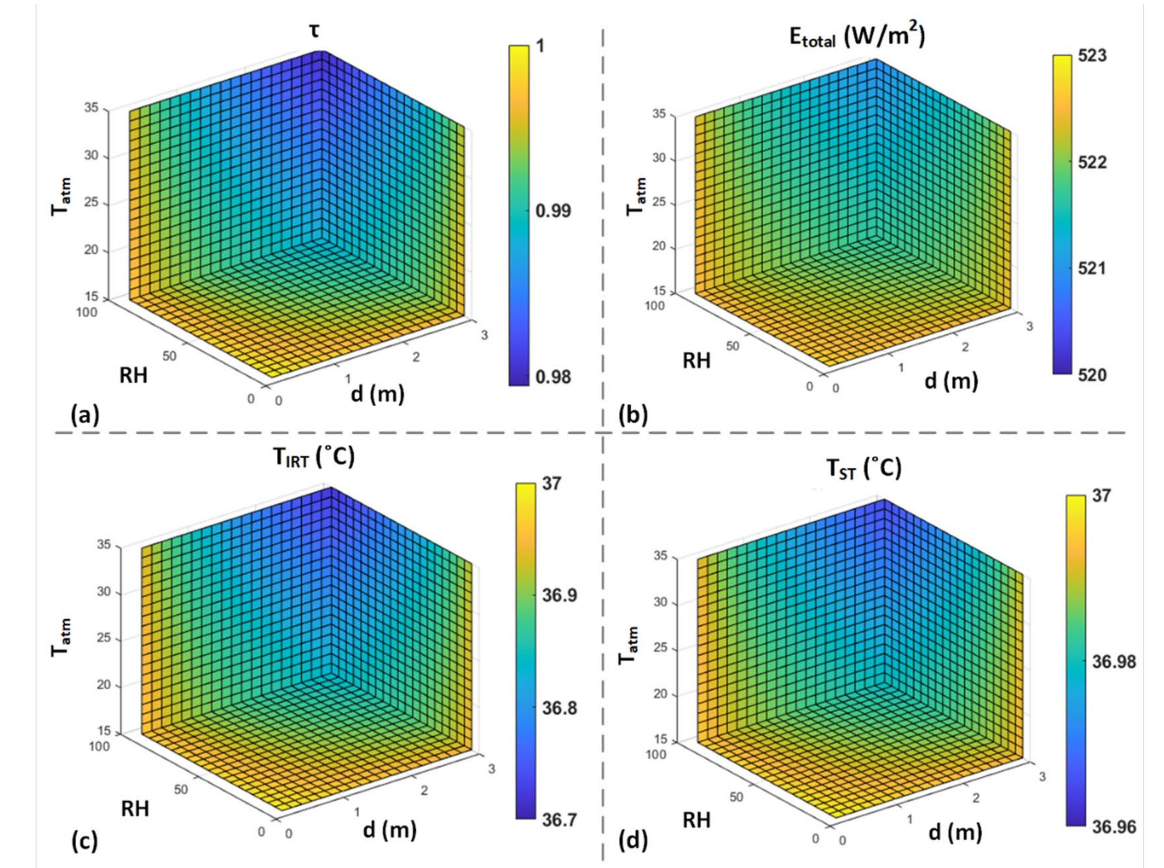

Fig. 7. Computer Simulation Results. (a) Atmosphere transmittance (τ) estimations for external factors. (b) The estimation of total radiosity/energy received by IRT. (c) Temperature estimation of a 37 °C object with the assumption of τ=1. (d) Temperature estimation of a 37 °C object with the τ=1 assumption with T_{ETRS}=35 °C.

Discussion and Conclusion

We conducted a series of benchtop measurements and computer simulations to address external factors relevant to the effectiveness and practical implementation of IRTs for EBT detection. Our study has shown that optimal IRT performance can be obtained when

- T_{ETRS} is set between 36 °C and 37 °C;
- Viewing angle is less than 30 °;
- Working distance is between 0.4 m and 2.8 m;
- Ambient temperature is between 18 °C and 32°C;
- RH is between 15% and 80%.

Our research into the performance evaluation of the IRT systems has provided significant insights toward the design of the least burdensome standardized test methods.

References

[1] Ghassemi et al., Best practices for standardized performance testing of infrared thermographs intended for fever screening. PLoS ONE 2018, 13, (9), e0203302, https://doi.org/10.1371/journal.pone.0203302.

[2] Zhou et al., Clinical evaluation of fever-screening thermography: impact of consensus guidelines and facial measurement location. Journal of Biomedical Optics 2020, 25, (9), 097002, https://doi.org/10.1117/1.JBO.25.9.097002 .

[3] Wang et al., Infrared Thermography for Measuring Elevated Body Temperature: Clinical Accuracy, Calibration, and Evaluation. Sensors 2022, 22, 215, https://doi.org/10.3390/s22010215.