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Effect of Ambient Temperature on Calibration of Cooled Thermal Camera

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ABSTRACT

Thermal cameras may be used under ambient conditions that differ significantly from the calibration conditions. The effect of ambient temperature on temperature measurement error is examined for MWIR and LWIR cooled thermal cameras. The facilities used include an environmental chamber and an extended area blackbody with temperature controller. Significant differences were observed in the temperatures measured by the cameras placed in different ambient temperatures, with reference to the set blackbody temperatures. Re-calibration was done to account for variations in ambient temperature from 5 ºC to on the outputs of the cameras. It was found that after such recalibration, the measurement error was within acceptable accuracy of ±1 °C.

Keywords: Calibration; Calibration drift; thermal camera; Ambient temperature

1. INTRODUCTION

Radiometrically calibrated thermal cameras are widely used for remote temperature measurements. These cameras measure the IR radiance of the object and derive the apparent temperature of the object using the calibration files provided by the manufacturer[1]. The calibration file is essentially created using a process where temperature reference is taken from a blackbody source[2].

Cooled thermal cameras are based on photon detectors and detector signal is proportional to number of incident photons per second from the sources as well as from the background[3]. Hence, the output of the cooled thermal camera depends on the background–i.e., the measurement conditions. A study of influence of measurement conditions on the accuracy of temperature measurement using thermal cameras was carried out by Chrazonwski[4-5]. The effect of various parameters–e.g., incorrectly assumed emissivity, background radiation reflected off the object, radiation emitted by the camera optics, limited atmospheric transmittance, and NETD, etc. on the accuracy of cooled thermal camera was simulated in this study[4-5]. The effect of measurement distance on the accuracy of temperature measurement through IR systems was also carried out by Chrazonwski[6]. These studies do not include the entire area of application of thermal cameras and limited to the in-door conditions with controlled environment. However, military applications of the thermal camera involve its use in different terrains under variable ambient conditions, which may differ appreciably from laboratory conditions. No study so far is known to have been carried out to ascertain the effect of ambient temperature on the accuracy of temperature measurement using thermal camera.

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Cooled thermal cameras are usually calibrated at room temperature and their usage under variable ambient conditions may induce error in temperature measurements due to calibration error[7]. This is why a thermal camera in cold climate does not perform as well as in hot or warm climate[8]. The field usage of thermal camera in the Indian scenario requires that it should perform over a range of ambient temperature conditions of summer and winter. A study has been carried out to quantify the deviation of measured temperature with respect to actual temperature under such ambient conditions. Further, a recalibration of the camera is carried out, so that it can be used in different ambient conditions with acceptable measurement accuracy.

2. GENERAL THEORY

Thermal cameras measure temperature indirectly from the Infrared radiation incident on the IR detector. The temperature of the object-under-view is determined on the basis of the absolute value of the measured optical signal[9]. The calibration process establishes the relationship between the temperatures and signal, incident on the detector, where a reference source simulates the tested object.

The calibration procedure used by commercially available cooled thermal camera is based on the creation of calibration characteristics at the manufacturer's site. The calibration characteristics are usually created for discrete set temperatures of blackbody (T_{bb}) at a fixed camera temperature. Two or three calibration characteristics are created by the manufacturer for the same set of discrete blackbody temperatures, at different fixed camera temperature.

The calibration of thermal camera is generally carried out in laboratory conditions where blackbody simulator serves as a reference source. During calibration the distance between the camera and blackbody (bb) source is kept short (less than one meter). When these conditions are satisfied, it can be considered that the influence of both, the limited transmittance of atmosphere and the radiation reflected by the reference source, is negligible[10]. This means that the camera receives only the radiation emitted by the blackbody and the radiation emitted by the optics, mechanical parts and the housing of the camera itself. Therefore, during calibration the Irradiance of thermal camera can be written as under:

$$L = L_{bb} + L_{cam} \quad (1)$$

where L_{bb} is the irradiance at camera emitted by blackbody and L_{cam} is the combined irradiance at camera, emitted by the various parts of camera e.g. optics, mechanical parts, housing etc.

The value of IR radiation at camera can be written as

$$L = \int_{\lambda_1}^{\lambda_2} M(T_{bb},\lambda)\tau_o(\lambda)s(\lambda)d\lambda + \int_{\lambda_1}^{\lambda_2} M(T_{cam},\lambda)[1-\tau_o(\lambda)]s(\lambda)d\lambda \quad (2)$$

where T_{bb} is the temperature of blackbody source, T_{cam} is the camera housing temperature, $M(T, \lambda)$ is the spectral emittance at temperature T and wavelength λ, $\tau_0(\lambda)$ is the average atmospheric transmittance and $s(\lambda)$ is spectral response of thermal camera.

As the radiation emitted by the various parts of the camera or we can say the camera housing temperature (T_{cam}) will be affected by different ambient temperatures so the room temperature calibration of thermal camera at fixed camera housing temperatures may not be valid with changes in T_{cam}. The significant change in camera housing temperature will produce an error in the temperature measured through the thermal camera.

3. INSTRUMENTATION AND METHODOLOGY

The schematic view of experimental setup, used in this study is shown at Fig. 1.

The experimental setup consists of the following equipment:

(i) Environmental chamber
(ii) Thermal camera
(iii) Extended area blackbody
(iv) Platinum resistance thermometer
(v) Blackbody controller.

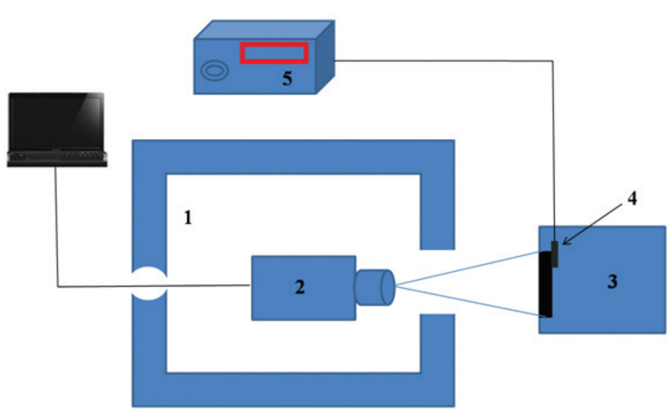

Figure 1. Schematic view of experimental setup.

3.1 Instrumentation

- Thermal camera: Make: CEDIP Infrared system, France; Detector: MCT; Array: 320 X 240; Wave band: MWIR (3.7 µm to 4.8 µm) and LWIR (7.7 µm to 9.5 µm), Optics: 50 mm, F/2; Software: Cirrus and ALTAIR
- Environmental chamber: Make: CM EnviroSystems Bengaluru, model: CLIMASTAT, Temperature range: -10 °C to 100 °C, test space: 1000 l
- Extended area blackbody sources: Make: CI systems, Israel; Temperature range: -5 °C to 125 °C; Emissivity: 0.97; Active area: 6″ X 6″

3.2 Methodology

The MWIR and LWIR thermal cameras were tested by keeping the camera inside the environmental chamber, at a focusing distance of about 1 m from the blackbody source. The temperature of environmental chamber, which is the ambient temperature for the thermal cameras, was initially set at 5 °C and increased in steps of 5 °C, up to 25 ºC.

For each setting of the ambient temperature, the temperature of the blackbody was increased stepwise from 5 °C to 60 °C with a step size of 10 °C, as measured by reference resistance temperature detector (RTD) sensor, attached with blackbody.

At each blackbody temperature setting, the blackbody source is allowed to reach steady state in about 5 min. The associated calibration file, supplied by the manufacturer, was used to perform non uniformity correction (NUC) for the camera. The thermal image of the blackbody source was captured. The camera housing temperature T_{Cam} for each set of measurements was also recorded.

The data collected was analysed as follows:

(i) An average area of 20 x 20 pixels is extracted from each of the recorded thermal images of blackbody source, to find the average digital level (DL) values and corresponding measured temperature (T_{meas}) for each set of blackbody temperatures, at each ambient temperature
(ii) The measurement error at each ambient temperature was estimated by calculating the difference as

$$\text{Error} = |T_{meas} - T_{bb}|$$

The measurement error may be positive or negative value but for the sake of simplicity, the absolute value of error has been taken.

Finally, the cameras were recalibrated for each ambient temperature with the creation of new calibration file using CF Manager tool of CEDIP[11]. The new calibration files were created by feeding DL values for a set of blackbody temperatures from 5 °C to 60 °C at different camera ambient temperatures.

4. RESULTS AND DISCUSSIONS

Figure 2 plots the variation of camera temperature (T_{Cam}) for MWIR and LWIR thermal camera with ambient temperature. It is seen from Fig. 2 that the ambient temperature affects significantly the camera temperature in both the bands i.e., MWIR and LWIR but the effect of ambient temperature on T_{Cam} is more in LWIR as compared to MWIR. This behaviour may be attributed to the fact that the radiation emitted from the various parts of the camera at

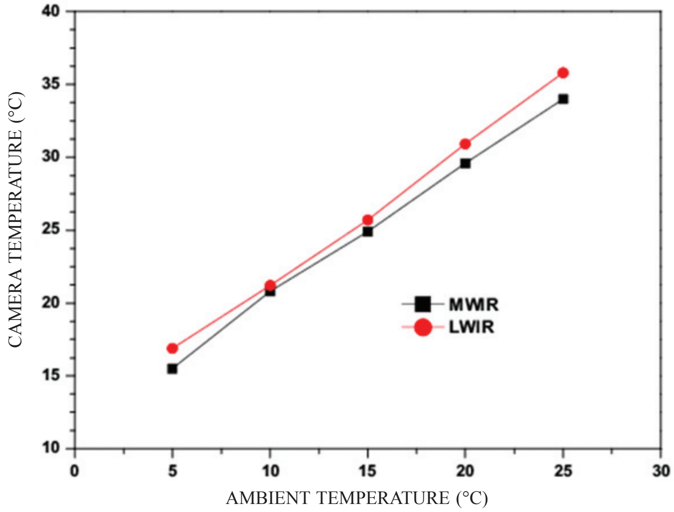

Figure 2. Variation of camera temperature (T_{Cam}) with ambient temperature.

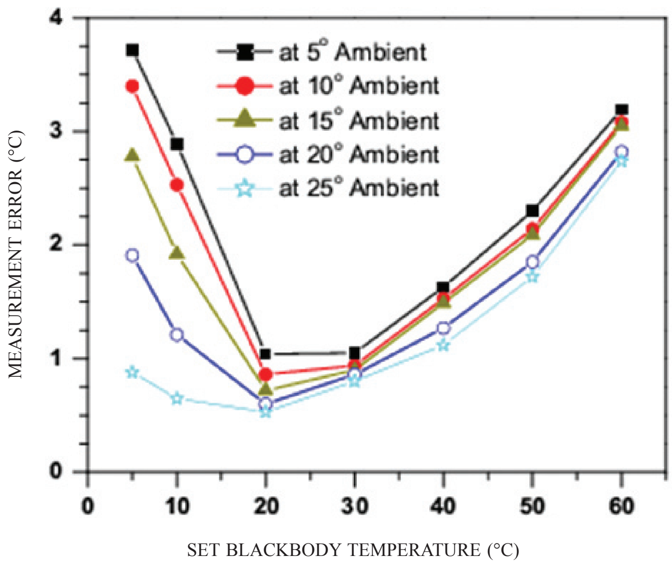

Figure 3. Absolute measurement error for MWIR camera at variable ambient temperature.

ambient temperature, as the LWIR camera is more sensitive to the radiation emitted by the objects at ambient temperature.

Figures 3 and 4 portray the absolute measurement error of MWIR and LWIR thermal camera against different set blackbody temperatures against the ambient temperatures. It is clear from Figs. 3 and 4 that the effect of ambient temperature on calibration is more significant for low ambient temperatures and as the ambient temperature increases the measurement error for each blackbody set temperature decreases. The error at lower blackbody temperature for lower ambient temperature is high because thermal camera, calibrated at room temperature requires more difference between object and ambient temperatures to provide the detector a sufficient radiation. The error for higher set temperature is high as the thermal camera receives large signal which ultimately leads to saturation of IR detector and further error.

Figures 5 and 6 represent the absolute measurement error of MWIR and LWIR thermal camera after the re-calibration

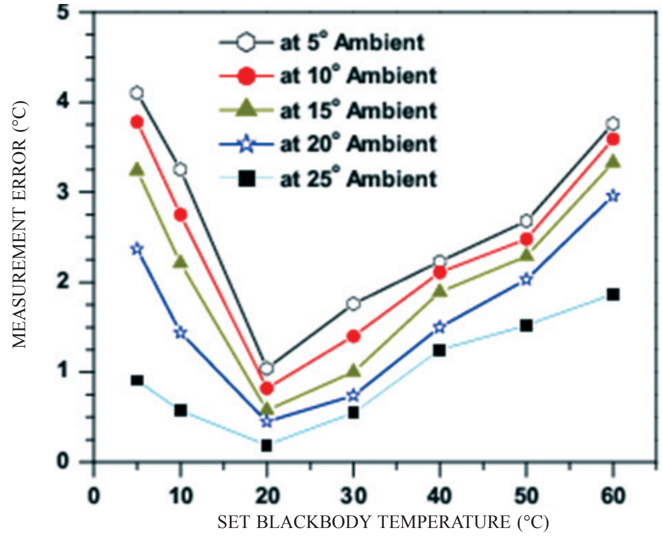

Figure 4. Absolute measurement error for LWIR camera at variable ambient temperature.

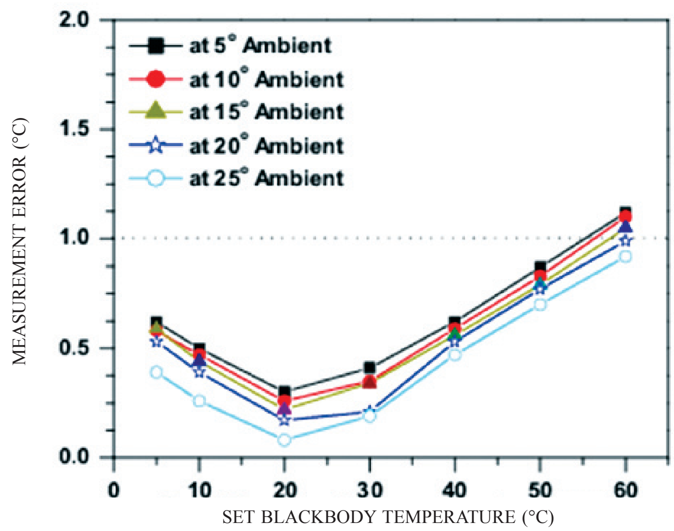

Figure 5. Absolute measurement error for MWIR camera after re-calibration.

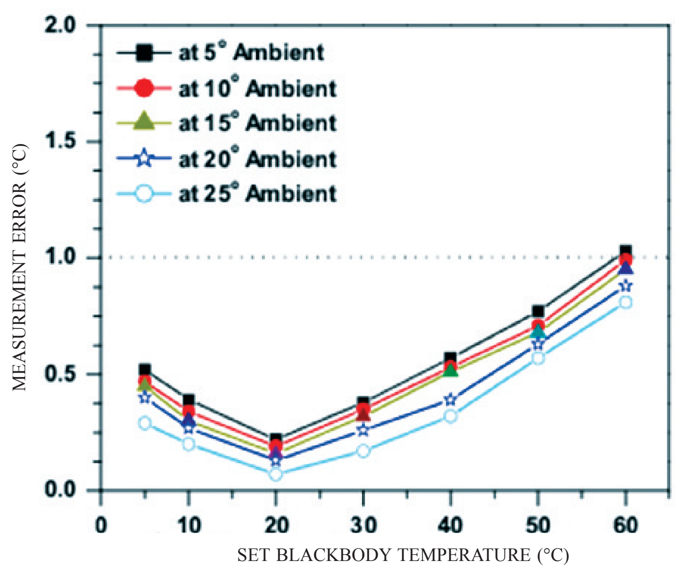

Figure 6. Absolute measurement error for LWIR camera after re-calibration.

at variable ambient temperatures with suggested methodology. The measurement error is within 1°C, which is in the specified accuracy of camera i.e. ±1 °C.

5. CONCLUSIONS

Ambient temperature significantly affects the calibration of the radiometric thermal cameras and results in measurement error when the camera is used in ambient conditions different from the calibration condition. Within the range of ambient temperatures between 5 °C and 25 °C, large differences (≤ 4 ºC) were observed between measured temperatures and the actual (set) temperatures. Re-calibration of thermal camera for different camera housing temperatures due to different ambient temperatures was seen to be effective in bringing down measurement errors within ±1 °C, which is of acceptable accuracy. This is useful for the usage of the thermal camera in outdoor conditions, over a range of ambient temperatures.

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His contribution in the current study is, in overall guidance during the work and conclusions through results.