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High Temperature Calibration of Thermal Imagers for Infrared Measurements on Military Platforms

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ABSTRACT

Calibration of thermal imaging system is not a straight forward process and hence manufacturers suggest re-calibration at factory itself. However, it is time consuming and expensive. A few research papers refer various approaches to perform low temperature calibration considering the wide requirement of low temperature measurements (typically less than 150 °C). However, no reference is available in open literature about high temperature calibration of thermal imagers. Hence, the possibility of high temperature calibration of thermal imaging systems has been explored using high temperature blackbody sources available at laboratory. With the use of neutral density filters, calibration has been performed in mid-wave (3.7 µm - 4.8 µm) and long-wave (7.7 µm - 9.5 µm) bands of imagers for IR measurements. The developed calibration has also been tested for field measurements.

Keywords: High temperature calibration; Thermal imagers; Infrared signatures and blackbodies

1. INTRODUCTION

Thermal imagers are array of non-contact thermometers used not only for relative but also absolute temperature measurements with spatial information. A thermal imaging system consists of optics, detector array, electronics, analog-digital (AD) conversion and image processing tools. The heart of each thermal imager is a detector array, which converts thermal radiation into electrical signal (usually voltage). The number of pixels in a focal plane array (FPA- detector array at focal plane) determines the spatial resolution of the thermal imager. Raw data/image in digital form (gray value/ digital level) is produced by an imager, when radiation from an object incident on the FPA. By applying calibration, this raw data/image is converted into radiometric data/image with temperature/radiance variation represented by pseudo colors.

For accurate and reliable temperature measurement with thermal imagers, a calibration with traceability to International Temperature Scale of 1990 (ITS-90)[1-2] is required. Calibration laboratories are commonly calibrating thermal imagers with the equipment and procedures developed for calibration of radiation thermometers[3-5]. To ensure that a device is operating satisfactorily, it is important that the device should be periodically calibrated. Calibration is a process that determines the relationship between the signal generated by the thermometer/ thermal imager and those (ITS-90) temperature values realised by the standard (in the case of thermal imagers, the standard is blackbody)[6]. In general, calibration of infrared thermometers/ thermal imagers is performed using well characterised, high precision blackbody (BB) standard reference sources[7].

Thermal imager is a ‘photon counting device’. Depending on the amount of photons received in a span of time (integration time), the detector generates an electrical voltage (V) expressed as digital level (DL). The photon/volt and volt/digital level transfer functions are dependent on the radiation incident on FPA. The purpose of calibration is to define this experimental transfer function. Depending on its type and configuration, the camera is sensitive to a certain range of photons. Sensitivity (or linearity) of the detector for a temperature range depends on integration time (IT) and the optical path (with/without filters). Hence, these two parameters decide the calibration in a temperature range, which is of user’s interest. In the present work, thermal imagers, for a wide range of temperatures (100 °C – 1600 °C) in both mid-wave and long-wave IR bands, were calibrated using cavity and extended area blackbodies. This facilitates field measurement of various military platforms using thermal imager.

2. EXPERIMENTAL SETUP, CALIBRATION PROCESS AND DATA COLLECTION

At first, integration time for the temperature range was determined from preliminary experiments. Criteria to determine integration time was followed by the procedure given by thermal imager reference manual[8] (DL range of detector: 3000-13000). Based on the integration time, the calibration ranges and the required calibration points were finalised. It was decided that the entire temperature range should be covered within three sets of calibration (or integration time), as it is the limitation of our imager. At high temperatures, the emitted radiant energy is

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very high that saturates the sensor/pixel array. Hence, neutral density filters (NDF) were used to attenuate the incident energy on the detector to perform calibration. In this case, 1 per cent and 10 per cent NDF filters having flat response in 2 µm - 14 µm waveband were used to calibrate mid wave (MW) and long wave (LW) thermal imagers respectively. These filters were mounted on the filter wheel in both the imagers and the incident energy is passed on to the detector through the filter.

The experimental setup for calibrating thermal imaging systems is as shown in Fig. 1. Focal length of a lens is associated with minimum focusing distance of an object in front of it. In this case, lenses with focal lengths of 50 mm as well as 200 mm were chosen for calibration. MFD for the same is 1m and 10 m, respectively. To perform non uniformity correction (NUC) and bad pixel removal (BPR) of the FPA, extended area blackbody (Make: Electro Optical Industries, Model: CES600-12-MG, Temperature Range: 50 °C – 600 °C) was used. For calibration process, the same extended area blackbody source was used up to 350 °C while cavity blackbody source (Make: LUMASENSE Technologies, Model: M330EU, Temperature Range: 300 °C - 1700 °C) was used above 350 °C.

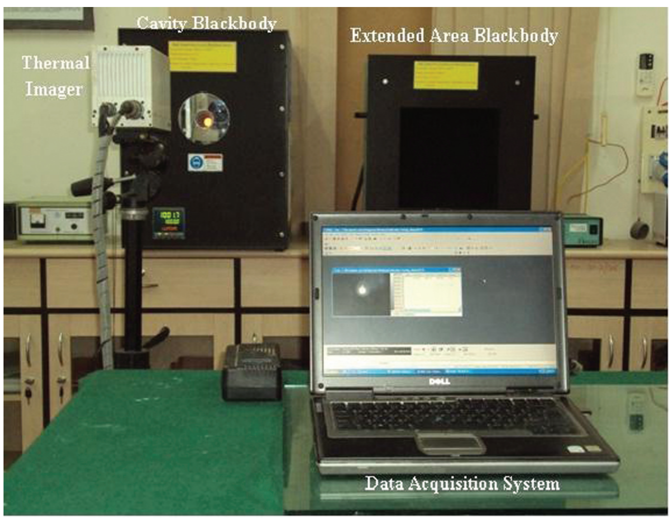

Figure 1. Experimental setup for calibrating thermal imaging systems.

2.1 Fixing of Dynamic Ranges and Integration Times

As the detector response is between 3000 DL - 10000 DL, the dynamic range of temperature needs to be defined to perform calibration. In the present case, the thermal range was decided to be 100 °C – 1600 °C. Based on the detector linearity, the thermal range was divided into three or four dynamic ranges and calibration was performed in every range. For determining the dynamic range corresponding to a calibration, initially the blackbody was set at highest temperature, i.e. 1600 °C in our case. After stabilisation of the blackbody at set temperature, the thermal imaging system was placed in front of the blackbody at MFD. Following the filter deployment in the field of view of thermal imager, a region of interest in the image was chosen for data acquisition. By hit and trial, an IT value was chosen to provide 13000 DL value to correspond 1600 °C (highest point of that dynamic range, say $R1_h$). For the same IT, the blackbody temperature was decreased to yield 3000 DL value (lowest point of that dynamic range, say $R1_l$) by the thermal imager. In this way, a dynamic range corresponding to a particular IT was determined. Thereafter, lowest temperature of previous dynamic range ($R1_l$) was fixed as highest temperature of new dynamic range (say $R2_h = R1_l$). Again IT and lowest temperature for this dynamic range were fixed in a similar manner as discussed. This process was continued till reaching the lowest temperature of 100 °C. In the present case, the whole range of temperature i.e. 100 °C – 1600 °C was divided into three dynamic ranges for MWIR thermal imaging system and two dynamic ranges for LWIR thermal imaging system. After identifying the dynamic ranges and their corresponding ITs, NUC and BPR processes were performed for all these dynamic ranges.

2.2 Generation of Non Uniformity Correction

Thermal imaging systems are equipped with a matrix made up of a multitude of detectors which are independent of each other. All detectors have disparate characteristics which affect the image quality[9]. Non Uniformity Correction is provided to compensate these disparities[10]. NUC is therefore essential to provide a coherent image. Every detector (with coordinates i and j) has its own gain (α_{ij}) and offset (β_{ij}) parameters, as shown in Fig. 2. NUC brings the gain and offset values of all detectors to an average gain and offset value. NUC is dependent on Integration Time (IT) and optical path. To perform NUC, thermal imaging system was placed in front of the extended area blackbody for 100 per cent fill factor. A 'Two Point' NUC was performed which corrects / equalises both gain and offset for all detector pixels in the FPA.

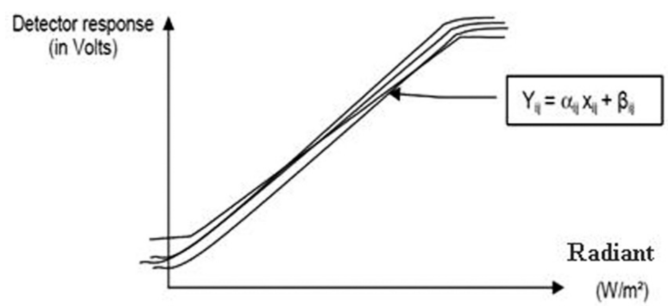

Figure 2. Photon detector response (voltage output) as a function radiant energy[8].

There are two methods to create NUC; first one is 'Blackbody Method' and the second one is 'Time Integration Method'. In the 'Blackbody Method', two blackbody reference points are needed. These references are taken at around 30 per cent and 70 per cent of the dynamic range chosen for calibration. In case of non-availability of two temperature references (as in our case, extended blackbody at a maximum of 600 °C is available), the 'Time Integration Method' can be used. In this case, for a fixed temperature, two integration times that corresponds to develop 6000 DL and 1000 DL values of the imager were determined as shown in Fig. 3. This process provides the required reference points to perform NUC.

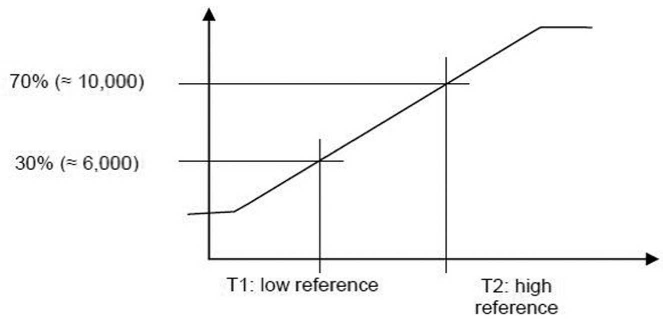

Figure 3. Development of NUC[8] using time integration method.

To employ time integration method, the extended area blackbody was set at a fixed temperature (400 °C) for performing NUC. The imager was placed in front of blackbody in such a way that the blackbody covers its field of view completely. As mentioned above, the ITs were determined and the NUC was performed for every calibration.

2.3 Generation of BPR

Due to the process involved in manufacturing detectors/ pixels, there exists defect in pixels of any FPA. The pixels with defect are called bad pixels. Furthermore, a pixel can also be classified as a bad pixel due to its noise level. These bad pixels are replaced by one of its non-defective neighbors through a software program to level the noise. This transformation is performed by the camera in real-time, after the NUC process. BPR for the calibration of all dynamic ranges was performed as suggested in user manual of Cedip thermal imaging system.

2.4 Calibration Data Collection and Curve Generation

In the calibration process, housing temperature of the imager was not taken into account. As mentioned earlier, extended area blackbody source was used for temperatures up to 350 °C and the cavity blackbody source was used for the rest. At least seven data points were chosen in every dynamic range to obtain DL values for generating calibration curve. Thermal imaging system was placed in front of the blackbody at a minimum focusing distance of 1 m and 10 m in the case of 50 mm and 200 mm optics, respectively. To reduce the influence of the camera's housing temperature, the camera housing temperature was stabilised by keeping the imager 'on' for a period of 2 h before collecting data points. The raw data was collected at different temperatures of dynamic range as per the process mentioned in user manual, Cedip thermal imaging system.

3. RESULTS AND DISCUSSION

Both MWIR (3.7 µm - 4.8 µm) and LWIR (7.7 µm – 9.5 µm) thermal imaging systems were calibrated up to 1600 °C for two lenses (focal length: 50 mm and 200 mm). As the present imagers can accommodate a maximum of three calibration ranges (integration times) at a time for simultaneous measurements, the entire temperature range of calibration (100 °C - 1600 °C) was divided into three set of dynamic ranges but in some cases. In this section, the results of all the calibrations are discussed.

3.1 Calibration of MWIR Thermal Imaging System with 1 per cent NDF and 50 mm Lens

In this case, the entire temperature range of calibration up to 1600 °C was divided into four dynamic ranges viz. 75 °C – 350 °C, 330 °C – 630 °C, 600 °C – 1200 °C and 800 °C – 1600 °C. A representative calibration curve of MWIR thermal imaging system with 50 mm lens for 330 °C – 630 °C dynamic range with IT of 2000 µs is given in Fig. 4.

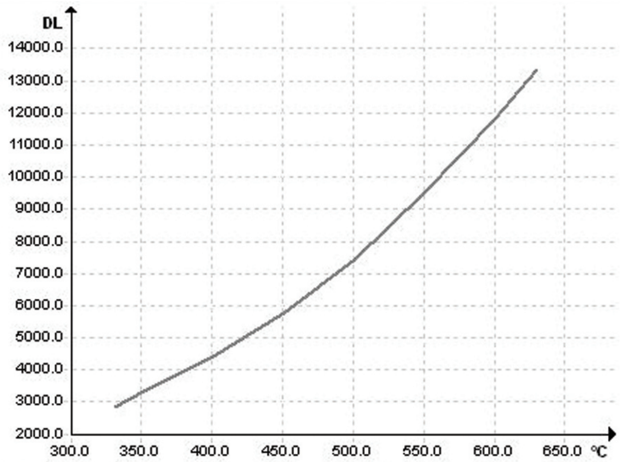

Figure 4. Calibration curve of MWIR imager (50 mm lens) for 330 °C - 630 °C.

3.2 Calibration of MWIR Thermal Imaging System with 1 per cent NDF and 200 mm Lens

In this case, the whole temperature range of calibration up to 1600 °C is divided into three dynamic ranges viz. 150 °C – 450 °C, 430 °C – 800 °C and 750 °C – 1600 °C. Here, the prominent temperature range (600 °C – 1200 °C) of aircraft plume was covered in two calibrations. Therefore, an additional calibration was done in this case to cover the above range with one IT. A representative calibration curve of MWIR thermal imaging system with 200 mm lens for 750 °C – 1600 °C dynamic range with IT of 330 µs is given in Fig. 5.

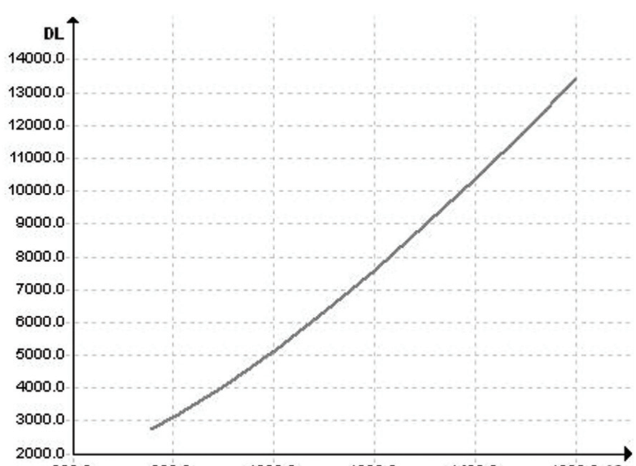

Figure 5. Calibration curve of MWIR imager (200 mm lens) for 750 °C - 1600 °C.

3.3 Calibration of LWIR Thermal Imaging System with 10 per cent NDF and 50 mm Lens

At high temperatures, LWIR band has less emitted radiant energy compared to MWIR band. Therefore 10 per cent NDF was used to calibrate LWIR imager. Also, the entire temperature range of calibration up to 1600 °C was covered in one dynamic range. The calibration curve of LWIR thermal imaging system with 50 mm lens for dynamic ranges of 100 °C – 1600 °C is given in Fig. 6.

3.4 Calibration of LWIR Thermal Imaging System with 10 per cent NDF and 200 mm Lens

The calibration curve of LWIR thermal imaging system with 200 mm lens for dynamic ranges of 100 °C – 1600 °C is given in Fig. 7. Complete details of dynamic ranges and their corresponding integration times (ITs) for both the thermal imaging systems are summarised in Table 1.

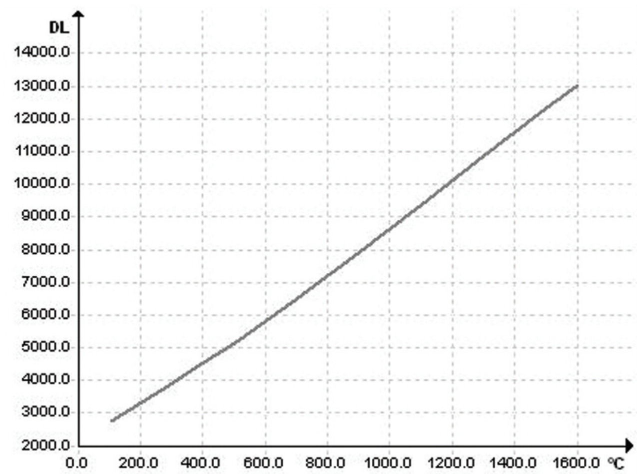

Figure 6. Calibration curve of LWIR imager (50 mm lens) for 100 °C - 1600 °C.

Table 1. Details of dynamic ranges and their corresponding integration times (ITs).

Thermal imaging system	Focal length of lens (mm)	Dynamic range (°C)	Integration time (µs)
MWIR	50	75 – 350	7500
		330 – 630	2000
		600 – 1200	440
		800 – 1600	230
	200	150 – 450	5500
		430 – 800	1470
		750 – 1600	330
		600 – 1200	600
LWIR	50	100 – 1600	120
	200	100 – 1600	130

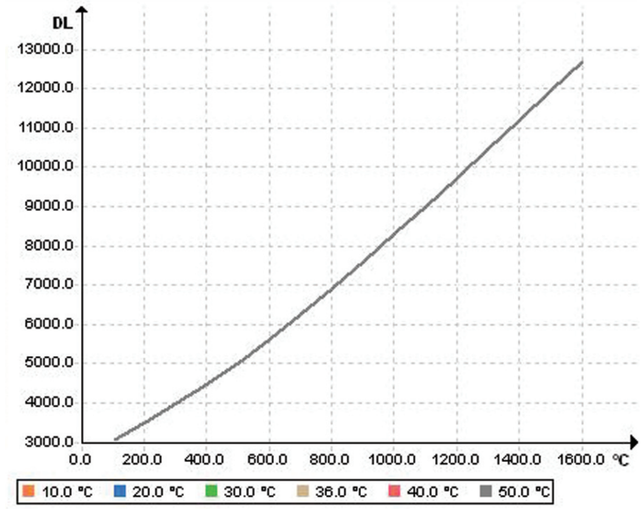

Figure 7. Calibration curve of LWIR imager (200 mm lens) for 100 °C -1600 °C.

4. CONCLUSIONS

High temperature calibration of thermal imagers for a wide range of temperatures (100 °C – 1600 °C) was carried out to assess IR signatures contribution of various military platforms. Both MWIR (3.7 µm – 4.8 µm) and LWIR (7.7 µm – 9.5 µm) thermal imaging systems were calibrated up to 1600 °C with two lenses (50 mm and 200 mm). To avoid the saturation of FPA at high temperatures, 1 per cent and 10 per cent NDF filters were used with lenses for the calibration of MWIR and LWIR systems respectively. The calibration of thermal imagers was performed using extended area as well as cavity blackbodies. NUC and BPR processes were performed to normalise the response of all the sensors/pixels of FPA and to replace the bad pixels respectively. The entire temperature range of calibration up to 1600 °C was covered in three dynamic ranges in the case of MWIR thermal imager. As the emitted radiant energy in LWIR band is low as compared of MWIR band, the entire temperature range of calibration up to 1600 °C was covered in one dynamic range in this case. The calibration thus developed has been used for IR signature measurements of military platforms.

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In present study, he performed experiments and analysed data. He developed calibration curves and drafted the manuscript.

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In this study, he designed the experiments for high temperature calibration. He also contributed in performing measurements and drafting of the manuscript.

Ms Karuna Poonia obtained her MSc (Physics) from University of Rajasthan, Jaipur in 2006. She has also obtained MTech in Opto Electronics & Optical Communication from Indian Institute of Technology (IIT), Delhi in 2010. She is presently working as Scientist 'B' at Defence Laboratory, Jodhpur. Her area of research is Infrared signature prediction. She is also involved in signature measurement and analysis of aircrafts.
In the present study, she participated in measurements and contributed in data analysis.

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In this study, he contributed in setting up the experiments and supported in data collection.

Dr J.P. Mangalhara did his MSc and PhD in Physics from IIT Delhi. Presently he is working as Scientist 'G' at Defence Laboratory, Jodhpur. His research area includes IR signature studies, IR camouflage system development, and thermal target system development.
In the present study, he contributed in data analysis and drafting of the manuscript.