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BLACKBODY AND PROCEDURE FOR CALIBRATION OF THERMAL IMAGERS

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Abstract: The article describes the bath with a large aperture blackbody, purposely designed and constructed for calibration of thermal imagers. For interpretation of experimental results and also for determination of inner blackbody temperature a numerical model was build. Based on available equipment a calibration procedure for thermal imagers was developed with special emphasis on evaluation of entire imager FOV.

Keywords: Thermal imagers, calibration procedure, homogeneity, entire Field-of-View

1. INTRODUCTION

For accurate and reliable absolute temperature measurement with thermal imagers, a calibration with traceability to International Temperature Scale of 1990 (ITS-90) is required [1,2]. Unfortunately, a general calibration procedure for thermal imagers is not yet defined and universally accepted. Calibration laboratories are commonly calibrating thermal imagers with the equipment and procedures developed for calibration of radiation thermometers. Such a calibration provides results only for a part of thermal imager's Field-of-View (FOV), while for the remaining part of FOV the same results are assumed, which may not be always true. From this point of view, an essential part of the calibration procedure should be a homogeneity evaluation of the entire thermal imager FOV.

For this purpose a calibration bath with a large-aperture blackbody was designed and constructed. Large aperture makes possible the evaluation of a thermal imager entire FOV. All detector elements are evaluated at the same time and under the same conditions.

2. THERMAL IMAGERS

Thermal imagers are non contact thermometers used for relative but also absolute temperature measurement. Basically they consist of optics, detector and detector electronics, AD conversion and image processing with output. The heart of each thermal imager is the detector, which converts radiation into electrical signal (usually voltage). In comparison to radiation thermometer (pyrometer), thermal imager detector consists of an array of elements, with typical resolution of 640×480 elements and more, Fig 1. Measured temperature field is represented by color image, where temperature value of each element has different color.

The FOV of a thermal imager is the projection of Focal Plane detector Array (FPA) at the target surface and Instantaneous Field-of-View (IFOV) is the projection of a single detector element, Fig.1.

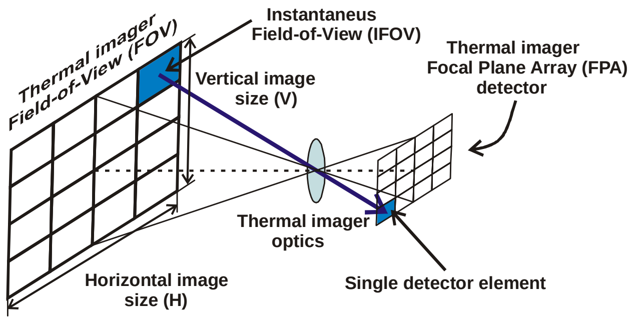

Fig.1: FOV and IFOV of thermal imager

Vertical image size (*V*) can be calculated in accordance with following equation:

$$V = d(2\tan(x/2)) \qquad (1)$$

where *d* is distance between the thermal imager and target and *x* is vertical angle of FOV given by manufacturer. Horizontal image size (*H*) is calculated similarly:

$$H = d(2\tan(y/2)) \qquad (2)$$

where *y* is horizontal angle of FOV.

At the same distance from target (*d*), the FOV of thermal imagers are much larger than FOV of radiation thermometers [3].

3. SUGESSTED CALIBRATION PROCEDURE

The suggested procedure for calibration of thermal imagers is divided in several tasks. At the beginning of procedure examination of the thermal imager should be performed. Every thermal imager at switching on needs a certain time to warm up and stabilise. Several temperature points are then selected within the entire calibration temperature range. A calibration measurement does not have to be taken in consecutive temperature points. For the linear approximation, measurements shall be performed at least at 4 different temperature points with the maximum difference of 200 °C between two successive temperatures in the same temperature range of a thermal imager. A thermal imager might have more than one temperature range, which are selected in the menu by using different filters. In general, during calibration each temperature range should be checked. The evaluation of the entire FOV should be performed in at least one temperature point, within the calibration temperature range. Also the dependence of results on the distance from the blackbody shall be analyzed. At the end the uncertainty budget should be given. Combined uncertainty of calibration is constructed of the three main groups of uncertainty sources. These are the uncertainties of the measurement of reference temperature, uncertainties of the blackbody emissivity and uncertainties associated with the thermal imager.

4. CALIBRATION BATH WITH A LARGE BLACKBODY

Thermal imager calibrations are performed using blackbodies, which are thermally stabilized inside calibration baths or furnaces and reference thermometers. In order to evaluate a large FOV of a thermal imager, a blackbody with a large aperture is required, so a calibration bath with a large blackbody was designed and constructed.

Calibration bath has a horizontally embedded large blackbody for calibration of thermal imagers and also radiation thermometers, Fig. 2. It has temperature regulation by means of a PID regulator in temperature range between −40 °C and +90 °C. The bath contains 150 litres of the working liquid, which can be either ethanol for the temperature range from −40 °C to +20 °C or water for the temperature range from +5 °C to +90 °C.

Fig.2: Calibration bath with a large blackbody

The blackbody cavity is a cylinder with the conical bottom of 120°. The cavity is 1120 mm long with the aperture diameter of 261 mm. The walls and cavity bottom are made of copper, painted with a high-emissivity black coating. This large aperture enables the positioning of the majority of commercial thermal imagers in such a way that the FOV is entirely inside the blackbody aperture.

Bath implements six individually-controlled valves for improvement of temperature stability and homogeneity of the bath along and around the blackbody cavity. The valves are used to manipulate the distribution of the flow of the working liquid along the length of the blackbody cavity. With adequate setting of valves the temperature homogeneity inside the calibration bath can be improved from approximately 100 mK to approximately 60 mK at bath temperature of 70 °C. The flow rate of working liquid inside the bath can also be adjusted by the power of the built-in circulation pump.

The blackbody has also an embedded system for purging the cavity with nitrogen gas in order to prevent the condensation of water vapour on the blackbody inner surface in cases when the set bath temperature is below the laboratory dew-point temperature.

The temperature field on the outer blackbody surface is measured permanently using the 20 built-in platinum resistance thermometers, Fig 3.

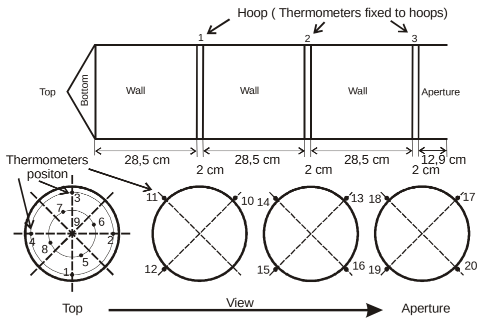

Fig.3: Position of resistance thermometers on the blackbody

Nine of them are positioned in the bottom, three on the first hoop, four on the second hoop and last four on the third hoop. The bath temperature stability is within 20 mK in the temperature range between +5 °C and +70 °C. Bath temperature homogeneity along the entire length of the blackbody is within 20 mK at room temperature and 60 mK at +70 °C.

5. NUMERICAL MODEL OF BATH

A numerical model of temperature gradients was designed in order to confirm and interpret the experimental results. Main focus of the numerical model was the analysis of the natural convection and its influence on the temperature of the inner surface of the blackbody, Fig 4.

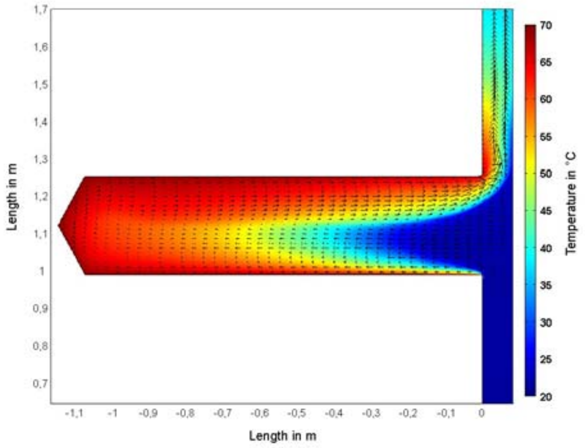

Fig.4: Natural convection inside of blackbody at set bath temperature of 70 °C and room temperature of 20 °C

The cold air on the lower part of blackbody gets in, cools down the inner surface and on the upper side leaves the cavity. We have calculated that convection does not influence the temperature field of blackbody.

Analyses were also performed regarding the influence of the flow rate of the working liquid, bath temperature and convective flux density. Numerical model was used to estimate the radial temperature gradient between the inner surface of the blackbody and the thermometers inside the bath. Obtained results are presented in Table 1. Radial gradient is increasing with increasing temperature difference between the set bath temperature and room temperature.

Table 1: Radial gradient at different bath set temperature and room temperature 20 °C

Set bath temp. in °C	Average temp. of inside thermometers in °C	Average temp. of inner surface in °C	Radial gradient in °C
-30	-29,898	-29,756	-0,142
-20	-19,927	-19,833	-0,094
-10	-9,954	-9,899	-0,055
0	0,023	0,046	-0,023
10	10,006	10,012	-0,006
20	20,000	20,000	0,000
30	29,993	29,989	0,004
40	39,978	39,962	0,016
50	49,954	49,920	0,034
60	59,922	59,868	0,054
70	69,883	69,808	0,075
80	79,839	79,743	0,096
90	89,796	89,688	0,108

Calculated temperature field on the inner surface of the blackbody was further used for calculation of the blackbody emissivity, which was performed using a program for emissivity calculation based on the Monte Carlo method. Calculated emissivity at set bath temperature of 70 °C and room temperature of 20 °C was at average 0.9997, for observation angle between 0° and 10°. Observation angle is defined between the geometrical axis of blackbody and the observation axis at the distance 1200 mm from the bottom.

Temperature measurements of the blackbody field were automated with the custom-made LabVIEW software application, which represents only a small part of the laboratory automation software [4].

7. CASE STUDY

As a case study, experiments were performed with the thermal imager ThermoPro TP8 manufactured by Wuhan Guide Infrared Technology. The thermal imager has an uncooled FPA microbolometer detector with an 8 µm to 14 µm operational wavelength and 384×288 pixel resolution. The thermal sensitivity is 0.08 °C at 30 °C. The specified accuracy is ±1 °C or ±1 % of reading in the temperature range between −20 °C to +250 °C. The imager FOV is defined with horizontal (*y*) and vertical (*x*) angle 22°×16°, and with a distance (*d*).

The position of thermal imager was set to two different distances. In the first case the distance between the imager and blackbody aperture was 20 cm. The imager was focused on aperture where according to radiation theory the emissivity is supposed to be almost 1. In this case the entire FOV was inside the blackbody cavity. The resulting image is presented in Fig.5. The homogeneity of the detector is 2.1 °C at set bath temperature of 70 °C and bath homogeneity of 60 mK.

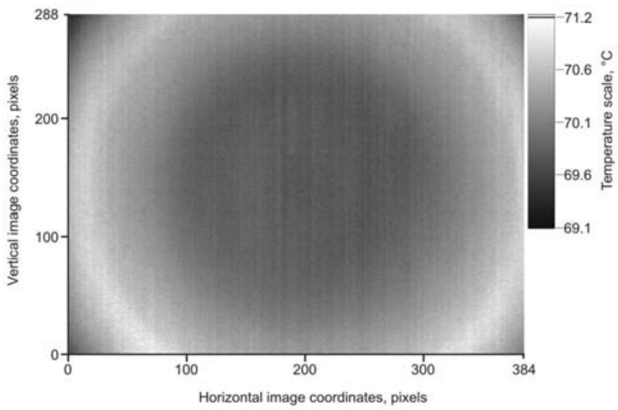

Fig. 5: Resulting image from the entire FOV image in front of the large blackbody, at temperature 70 °C and focus distance of 20 cm

In the second case the distance between the imager and the aperture of blackbody was set to 75 cm, with focusing to aperture. At this distance only a part of entire FOV is inside of the cavity. The imager entire FOV was assembled from 4 smaller images, which were individually positioned in front of the blackbody aperture and evaluated. Assembled resulting image is presented in Fig. 6. Results are similar to privies one, detector homogeneity is about 1.7 °C. It can be observed slightly colder area in the centre and in the corners of the image. This temperature drop can be observed in each of the measurement cases and with varying intensity at different set temperatures and focus distances, so it is clearly an error of the thermal imager.

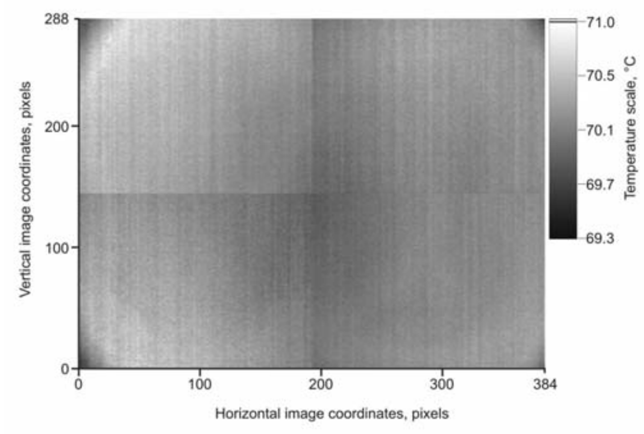

Fig. 6: Entire FOV assembled of 4 images, individually positioned in front of the large blackbody, at temperature 70 °C and distance of 75 cm

The positioning of the thermal imager in front of the blackbody aperture was performed using an automated spatial positioning system, fig. 7. Positioning system has three translation joints and two rotation joints. It is composed of three main parts, which are the main frame, the central moving part and the control unit, [5]. Additionally, the system requires a serial connection to personal computer, where the user interface was programmed as a virtual instrument in LabVIEW programming environment.

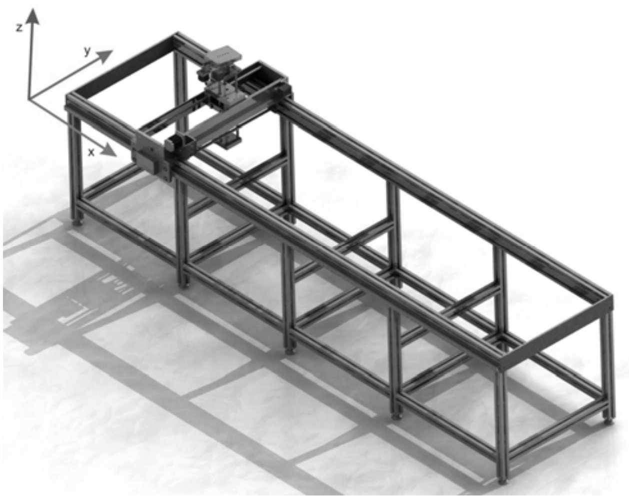

Fig. 7: Automated spatial positioning system

The outer dimensions of the system are: length x axis (3000 mm), width y axis (850 mm), and height z axis (1200 mm). The operating range of the rotation joint R1 is 11.5°, the rotation joint R2 is 20°, the translation joint x is 280 cm, the translation joint y is 50 cm, and the translation joint z is 30 cm. The workspace of the positioning system was set to fit available laboratory space and fulfil requirements of positioning as a support operation for other measurement procedures.

The inhomogeneity of the thermal imager under test is within specified accuracy, except in the image corners, where a drop of the measured temperature was noticed.

8. CONCLUSIONS

The aim of this paper was to present the developed large-aperture blackbody and its performance. Such a blackbody was applied in calibration procedure for thermal imagers. The main idea of calibration is evaluation of the entire imager FOV. Evaluation of the entire FOV of the thermal images is essential in order to produce reliable calibration results. Presented evaluation of the entire FOV can be very useful also for the manufacturers of thermal imagers, because a product cannot achieve a level of high quality, if its properties cannot be properly measured.

The calibration bath with a large aperture blackbody was constructed for evaluation of entire FOV of a thermal imager. The temperature homogeneity of the blackbody can be improved with 6 bath valves. Convection in blackbody is within reasonable limits and does not influence the temperature field. Measured radial gradients were taken in consideration in calculation of blackbody emissivity. The system for prevention of condensation in blackbody's cavity is only partially effective. At set temperatures of the bath below the dew point, the condensation of water vapour begins to accumulate on the inner surface and with this the emissivity of the blackbody may change.

9. REFERENCES

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