Infrared Physics & Technology 54 (2011) 92–99

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Calibration and verification of thermographic cameras for geometric measurements

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ARTICLE INFO

Article history:
Received 2 November 2010
Available online 27 January 2011

Keywords:
Thermography
Thermal sensitivity
Metrology
Verification
Standard artefact

ABSTRACT

Infrared thermography is a technique with an increasing degree of development and applications. Quality assessment in the measurements performed with the thermal cameras should be achieved through metrology calibration and verification. Infrared cameras acquire temperature and geometric information, although calibration and verification procedures are only usual for thermal data. Black bodies are used for these purposes. Moreover, the geometric information is important for many fields as architecture, civil engineering and industry.

This work presents a calibration procedure that allows the photogrammetric restitution and a portable artefact to verify the geometric accuracy, repeatability and drift of thermographic cameras. These results allow the incorporation of this information into the quality control processes of the companies. A grid based on burning lamps is used for the geometric calibration of thermographic cameras. The artefact designed for the geometric verification consists of five delrin spheres and seven cubes of different sizes. Metrology traceability for the artefact is obtained from a coordinate measuring machine. Two sets of targets with different reflectivity are fixed to the spheres and cubes to make data processing and photogrammetric restitution possible. Reflectivity was the chosen material propriety due to the thermographic and visual cameras ability to detect it.

Two thermographic cameras from Flir and Nec manufacturers, and one visible camera from Jai are calibrated, verified and compared using calibration grids and the standard artefact. The calibration system based on burning lamps shows its capability to perform the internal orientation of the thermal cameras. Verification results show repeatability better than 1 mm for all cases, being better than 0.5 mm for the visible one. As it must be expected, also accuracy appears higher in the visible camera, and the geometric comparison between thermographic cameras shows slightly better results for the Nec camera.

1. Introduction

Thermography is the technique of producing an image from the infrared radiation that all the bodies emit due to their thermal conditions [1]. This technique has an increasing development, with a wide variety of applications, such as building inspection, both new and historic [2–4], linear structures [5,6], electric and mechanic maintenance [7,8], renewable energies [9], process monitoring [10], human and veterinary medicine [11–14], and animal detection [15].

Thermographic cameras are typically thermally calibrated and verified in order to guarantee an accurate temperature measurement. These calibrations and verifications are based on black bodies, which avoid spurious radiation reflectivity, and generate controlled temperature conditions with traceability to the national reference, Kelvin. Calibrations and verifications based on black bodies are a mature metrological service that is offered by many laboratories around the world.

Geometric information of thermographic cameras obtained from photogrammetric restitutions could be very important in many fields (energy efficiency studies in architecture, geometrical positioning of concrete pathologies in civil engineering, process monitoring in injection mould and machining, mechanical wear prediction, electrical failure detection, etc.). Moreover, geometric calibration and verification of thermographic cameras is scarcely found in the bibliography [16], in comparison with the metric calibration of photographic visible cameras which is very common [17,18].

The importance of combining thermal and geometric data from the cameras and the necessity to integrate the instrumentation in the quality management systems of the companies make it necessary to develop calibration procedures and standard artefacts for the geometrical verification of these systems.

This work shows a calibration procedure and a low-cost, portable system to verify the geometric parameters, such as accuracy, repeatability and drift, of thermographic cameras. Such procedure

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doi:10.1016/j.infrared.2011.01.002

and artefact are used to establish the geometrical calibration and verification of two thermographic cameras, Flir P640 and NEC TH9260, both with sensors of 640 × 480 pixels, and a semi-metric visible camera, Jai BB500GE.

2. Experimental

2.1. Cameras

Two thermographic cameras from different manufacturers but similar characteristics are analyzed in this paper. Their technical characteristics are shown in Table 1, and an image of them is shown in Fig. 1a and b.

The semi-metric visible camera used was a Jai BB500GE, with 8 mm lens. Its technical specifications are shown in Table 2, together with an image of it (Fig. 1c).

2.2. Camera calibration

Camera calibration is a key aspect to obtain geometrical information through photogrammetry restitution. Calibration gives the internal parameters of the camera as the focal length, principal point or lens distortion. For both semi-metric and thermographic cameras, calibration is performed by a self-calibration bundle adjustment method [17,18], by taking several images of a calibration grid. The calibration files from each camera would be used in the model's restitution project. Both calibration and model's restitution projects were developed using Photomodeler software, which is a photogrammetric station which allows obtaining the three-dimensional position of points on the surface of objects from a minimum of three photographs of it.

2.2.1. Photogrammetric camera's calibration

The Jai BB500GE camera was calibrated using Photomodeler software and calibration grid. This method is extensively used in visible camera calibration [19–21] and is shown next, with the following procedure:

1. Selection of type and size of the calibration grid used (Fig. 2).
2. Capture of eight photographs of the calibration grid, from different points of view, which must ensure good ray intersections. Therefore, images should be taken perpendicularly and obliquely from the calibration grid, with a relative rotation of 90° around the optical axis [22].
3. Photomodeler processing: automatic fiducial targets marking, calibration algorithm.
4. Generation of a file including the calibration parameters, that are focal length, format size, principal point and radial and decentering distortion of the lens. Values of these parameters for Jai camera are shown in Table 5.

Table 1
Technical characteristics of the thermographic cameras used in this paper.

Camera	NEC TH9260	FLIR P640
Temperature range	−20 to +500 °C	−40 to 500 °C
Thermal sensitivity/NETD	0.06 °C @ +30 °C	0.03 °C @ +30 °C
Detector	640 × 480 UFPA	640 × 480 UFPA
Spectral range	8–14 μm	7.5–13 μm
Spatial resolution/IFOV	0.6 mrad	0.65 mrad
Field of view/FOV	21.7° (H) × 16.4° (V)	24° (H) × 18° (V)
Image frequency	30 Hz	30 Hz

Table 2
Technical specifications of the Jai camera given by the manufacturer.

	Jai BB500GE
Sensor type	CCD
Sensor size (mm)	8.45 × 7.07
Pixels	2456 × 2058
Pixel depth (bits)	12
Frame rate (fps)	15
Lens focal length (mm)	8
f-Ratio	1.4

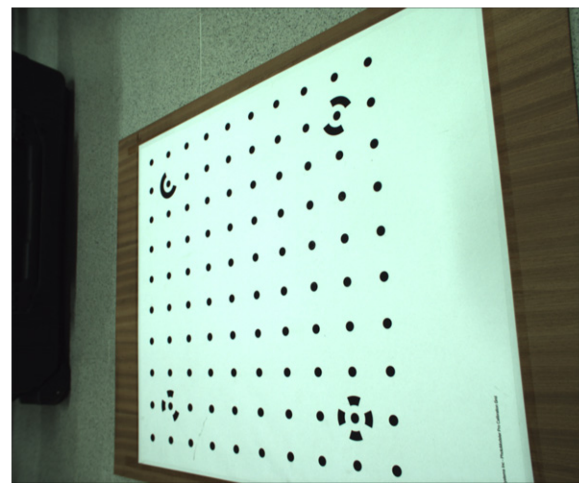

Fig. 2. Calibration field taken with camera Jai BB500GE.

2.2.2. Thermographic cameras' calibration

Thermographic cameras are thermally calibrated in order to provide accurate temperature information [23], but there is not much information about their metric calibration for geometrical purposes. A calibration field was designed with the objective of serving as a calibration field for thermographic cameras. This field consists of a wooden plank, with a surface of 1 m^2, with 64 burning lamps, chosen due to their suitability for being detected by the

Fig. 1. Cameras used in this project: (a) Flir P640, (b) NEC TH9260, (c) Jai BB500GE.