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Configuration of systems for testing thermal imagers

Krzysztof CHRZANOWSKI[1, 2*], Xianmin LI[3]

[1]Military University of Technology, Institute of Optoelectronics, Kaliskiego 2, 00-908 Warsaw, Poland

[2]Inframet, Graniczna 24, Kwirynów, 05-082 Stare Babice, Poland

[3]Beijing Institute of Technology, 5 South Zhongguancun Street, Haidian District, Beijing 100081, P.R. China

[*]Corresponding author: kchrzanowski@wat.edu.pl

Systems for testing thermal imagers offered commercially are built from the same modules: an off-axis reflective collimator, a motorized rotary wheel, a set of IR targets, a black body, a black body/wheel controller, a PC and some software. The classical solution is that all these components are located horizontally on an optical table. However, it is also possible to use a vertical configuration of the test system when the rotary wheel is put on the collimator and the black body is put on the rotary wheel. It was shown in this paper that when the vertical configuration is used, then better temporal stability and spatial uniformity of the thermal images projected by the test system can be achieved.

Keywords: thermal imaging, infrared, metrology.

1. Introduction

Test systems and methods for testing thermal imagers have been developing for the last forty years parallel with the development of thermal imaging technology. There are some standards and a vast literature on the subject of testing thermal imagers [1–4]. Basically, all literature references recommend to use for testing thermal imagers a modular test system built from the following modules: off-axis reflective collimator, motorized rotary wheel, set of IR targets, black body, black body/wheel controller, PC, and some software for image acquisition and data analysis. All these components are located horizontally on an optical table, as shown in Fig. 1. The test systems available on the market are built as modular systems according to earlier mentioned literature recommendations [6–10].

The test system projects images of targets fixed to a rotary wheel using an off-axis reflective collimator as an image projector. The tested thermal camera is located at the output of IR collimator and the target at the collimator input (the focal plane).

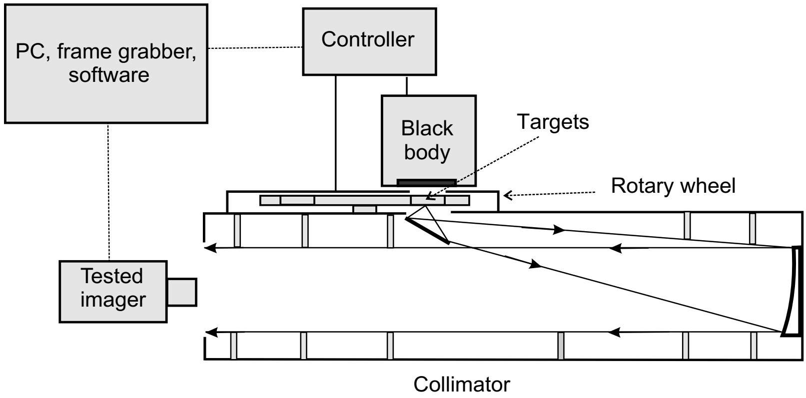

Fig. 1. Block diagram of a typical system for testing thermal imagers (horizontal configuration – vertical view).

The distance between the target and tested camera is very short and usually not within focusing range of typical surveillance thermal imagers. However, due to the use of the collimator, the imager "sees" the target as a very long-distance object, that is within its focusing range. A series of targets is fixed to the rotary wheel. By rotating the wheel, it is possible to exchange quickly the targets. By changing target dimensions, the changes of distance are simulated.

The task of the test system for testing thermal imagers is to generate images of some standard static targets of the precisely known shape, dimensions and temperature distribution. The tested imagers generate distorted images of the original ideal targets images. Next, the images generated by the tested imagers are evaluated and important characteristics of the tested imagers are determined.

The distortion of the final output image is caused by both the tested imager and by the limited performance of the test system. We can test accurately thermal imagers only when distortion of the final output image caused by the test system is negligible in comparison with distortion caused by the tested imager.

The distortion can be divided into two types. First, geometric distortion causes some blurring of the image and image digitalization. Second, radiometric distortion adds some noise and non-linear conversion of target temperature to image brightness.

2. Requirements on the test systems

The presented earlier concept for testing thermal imagers has been used for several decades and can be treated as experimentally verified. Undoubtedly, there are no reasons for trying to change anything in this well working concept. However, the technology of thermal imagers has improved rapidly during the last decade. There are commercially available cooled thermal imagers capable to resolve 4-bar targets of temperature difference below 10 mK. For non-cooled thermal imagers this limit is increased to about 40 mK. In both cases we can say that modern thermal imagers are capable to see very small temperature differences. If temporal or spatial fluctuations of temperature on the surface of the black body (or surface of targets) can be detected by a tested imager, then we will measure imager parameters with some errors due to limitations of the test system. Therefore, limited temporal stability and temperature uniformity of black bodies and targets were identified as factors that can limit accuracy of testing sensitive thermal imagers over a decade ago with advent of staring cooled imagers [5].

It is commonly accepted that temperature resolution, temperature stability and temperature uniformity of black bodies used testing thermal imagers should be at least five times better than temperature resolution of tested thermal imager. Noise equivalent temperature difference (NETD) parameter is usually treated as temperature resolution of thermal imagers. Therefore, we can present requirements on black body for testing thermal imagers in the form

$$\text{NETD} \geq 5\,\text{TR} \quad \text{and} \quad \text{NETD} \geq 5\,\text{TS} \quad \text{and} \quad \text{NETD} \geq 5\,\text{TU} \tag{1}$$

where TR is temperature resolution, TS is temporal temperature stability, and TU is spatial temperature non-uniformity.

When we analyze the websites of manufacturers of equipment for testing thermal imagers [6, 10], we find that in most cases they offer black bodies of the following parameters: temperature resolution – 1 mK, temperature stability – ±3 mK, and temperature uniformity – <10 mK at $\Delta T < 5$ °C (ΔT is temperature difference between black body temperature and ambient temperature) [6–10].

Temperature uniformity refers to the whole area of a black body emitter. During tests of thermal imagers only a fragment of the black body emitter is seen. Next, temperature difference between a black body and a target is nowadays rarely over 200 mK during real tests. Therefore we can assume that the "perceived" temperature uniformity of the black body is much smaller than the value presented in data sheets as the maximal value. We can estimate that temperature uniformity is on the same level as temperature stability (±3 mK). We can then conclude that the criterion (1) cannot be fulfilled during tests of cooled thermal imagers of very good temperature resolution NETD below 15 mK because of too poor temporal temperature stability and temperature spatial non-uniformity. Therefore, it would be desirable to improve temperature stability and temperature uniformity of black bodies for testing thermal imagers.

3. Performance improvements

A typical way to improve temperature stability of a black body emitter is to reduce the analog noise in the electronics of the black body controller, increase the dynamics of the A/D converter, and to improve the stabilization algorithm [11, 12]. Next, temperature uniformity of the black body can be improved by increasing mass of the black body radiation, but such a solution can also reduce black body speed (longer stabilization time). There are also several other technological solutions to improve both temperature stability and temperature uniformity of the black body. However, in all cases, we are talking about introducing some costly technological changes to a standard line of black bodies used in systems for testing thermal imagers. We must remember that the equipment for testing thermal imagers is already very expensive and prices can reach the level of one hundred thousand US dollars. Therefore, more desirable is to find a solution how to improve temporal stability and temperature uniformity of the black body without making any technological changes of typical test systems.

It has been mentioned earlier that the test systems are typically arranged as a series of separate modules placed on a big optical table. Fluctuations of atmospheric air have free access to all components of the system, including the black body and the targets (Fig. 2) [8]. A law of physics states that warmer air goes up and cold down. Therefore air fluctuations caused by changes of black body temperature and variation of temperature in the room take place along the surface of the black body and the surface of the targets all the time. In this way, even if we have a perfect black body of temporal stability and temperature uniformity equal to zero, the air fluctuations shall generate some temporal non-stability and temperature non-uniformity that can be perceived by a sensitive thermal imager.

Some manufacturers put the black body, the wheel and the targets into a plastic enclosure to reduce the influence of air fluctuation on temporal stability and spatial uniformity of temperature distribution on the surface of the black body and the targets used in the test systems [6]. This is an effective way to eliminate the influence of fluctuation outside the chamber. However, the air fluctuation inside the chamber generated due to natural vertical temperature non-uniformity of air layers can still reduce temporal stability and spatial uniformity of temperature distribution on the surface of the black body and the targets.

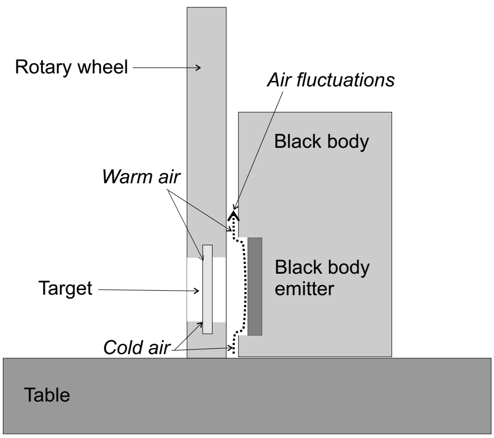

Fig. 2. Air fluctuations at surfaces of the black body and the target of the test system of horizontal configuration.

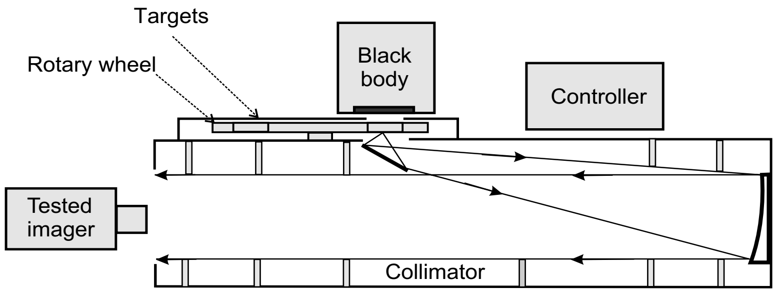

Fig. 3. Block diagram of a typical system for testing thermal imagers (vertical configuration – horizontal view).

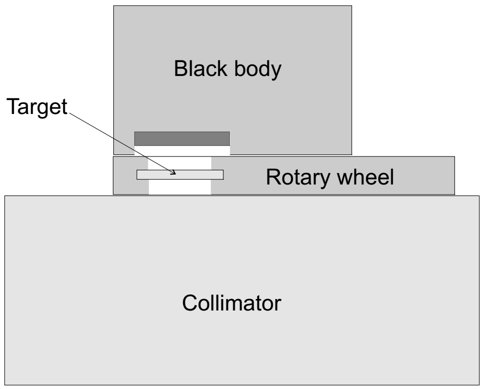

Fig. 4. The black body, the rotary wheel and the targets of the test system of vertical configuration.

A new solution to reduce the influence of air fluctuation on temporal stability and spatial uniformity of temperature distribution on the surface of the black body and the targets used in the test systems is shown in this paper. It is proposed to use a vertical configuration of the test systems as shown in Figs. 3 and 4. The black body is located over the rotary wheel with targets. The black body has a direct thermal contact with the rotary wheel with the targets, the wheel has a direct thermal contact with a collimator.

The tests of thermal imagers are typically carried out for positive contrast of images generated by the tested imager system (after the offset of the black body is corrected). The positive contrast means that temperature of the black body is slightly higher than temperature of the targets and the rotary wheel. For such a situation a stable layer of warm air is created below the surface of the black body radiator. The targets are within a stable layer of a bit cooler air. If the temperature of the black body radiator and the temperature of the targets are stable, then there are no interactions between the mentioned above layers. Now, there are no air fluctuations that reduce temporal stability and spatial uniformity of the black body perceived by the tested imager. In this way, without any technological changes of the black body we improved its temporal stability and spatial uniformity.

4. Experimental verification

To verify the hypothesis that by changing configurations of modules of the system for testing thermal imagers we can significantly improve temporal stability and spatial uniformity of the black body perceived by the tested imager, several experiments were carried out. A commercially available DT 1500 test system (built from CDT 1500 collimator, TCB-2D black body, MRW-8 wheel, set of targets, PC, frame grabber, TAS-T software) from Inframet company, capable to work in both configurations, was used for these experiments.

The simplest way to verify the hypothesis would be to record the images of the black body and the targets at two different test configurations using measurement commercial imagers designed for non-contact temperature measurements. However, typical commercial non-cooled thermal imagers cannot be used to measure temperature distribution of so low amplitude (below 10 mK) because their resolution (typically 100 mK) is several times higher than the expected amplitude of temperature distribution. Special cooled commercial staring thermal imagers of temperature resolution close to 10 mK were not available for the authors of this paper. Therefore, several experiments that indirectly verify the hypothesis were carried out.

First, the TCB-2D black body was inserted into the DT 1500 test system having horizontal configuration as shown in Fig. 1. We waited for about 15 minutes and then the black body was set to stabilize temperature difference equal to +2 K. After about 60 s the differential temperature indicated by the black body controller was stabilized in the range of +2 K ±0.003 K. Next, the same TCB-2D black body was inserted into DT 1500 test system having vertical configuration as shown in Fig. 3. We waited for about 15 minutes and then the black body was set to stabilize temperature difference equal to +2 K. After about 60 s the differential temperature indicated by the black body controller was stabilized typically in the range of +2 K ±0.001 K.

Second, an MRTD parameter at low frequency of a cooled staring surveillance thermal imager* was measured using the test system at both configurations. The tests were carried out for MW staring cooled thermal imager at 0.22 lp/mrad spatial frequency. The imager was working in the narrow field of a view mode: $1.8° \times 1.4°$ and the maximal gain setting was used. The measurement MRTD results are the following: 13 mK for the horizontal configuration; 9 mK for the vertical configuration. Additionally, when the image of 4-bar targets was clearly more stable in case of vertical configuration. In case of horizontal configuration there were moments when the observer could see and resolve the 4-bar target but there were also moments when the target could not be detected.

* The type of the imager and the manufacturer name cannot be disclosed because the presented test results are a by-product of commercial tests carried out by the authors.

Third, the same cooled staring surveillance thermal imager was used to generate images of TCB-2D black body at two different system configurations. The black body was set for differential temperature equal to 0.1 K. The observations were made just after the non-uniformity correction operation was done for the imager. When the 4-bar target was removed and the imager could see the full area of the black body emitter, then in case of horizontal configuration we could clearly see some spatial non-uniformities on the black body surface. Next, these non-uniformities were changing with time. In case of the vertical configuration these non-uniformities were barely visible.

The differences between the images of TCB-2D black body generated by the thermal imager in two different configurations are clearly visible using bare eye when looking on live video sequence. The differences are difficult to notice in case of static printed images. Therefore, the authors could not print captured images to prove that temperature variations of the surface of the black body are significantly lower in case of the vertical configuration.

When the black body is filling a significant part of imager field of view (FOV), then spatial non-uniformity of the black body generates the same effect as spatial non-uniformity of infrared focal plane array (IR FPA) used in the thermal imager. Therefore, the authors carried out typical measurements of spatial non-uniformity using typical test procedures but they limited the analyzed area to the area filled by the black body (about 12% of imager FOV). The measurement results are the following: 21 mK for the horizontal configuration and 13 mK for the vertical configuration (see the Table).

T a b l e. Summary of test results.

Parameter	Test system configuration	
	Horizontal	Vertical
Black body temporal stability [mK]	±3	±2
MRTD at 0.22 lp/mrad [mK]	13	9
Spatial temperature non-uniformity [mK]	21	13

The results from the first experiment show that by changing configuration of the test system we can improve temporal temperature stability of the black body to the level when the condition (1) is fulfilled for thermal imagers of temperature resolution NETD bigger than 10 mK; practically for all commercially available thermal imagers.

The situation is not so clear when we analyze results of the second experiment and the third experiment. These results show directly that by changing configuration of the test system we can get better MRTD test results at low spatial frequencies range and that the spatial non-uniformity of IR FPA (when testing very sensitive thermal imagers) is lower. We can conclude indirectly that these significantly better results of tests of thermal imager originate from significantly improved spatial temperature non-uniformity of the black body of the test system. It is not clear how much spatial non-uniformity of the black body can be improved by changing configuration of the test system as the authors could not find an accurate way to separate from the result of the third experiment the two components: spatial non-uniformity of the black body and spatial non-uniformity of the imager. However, it is highly probable that by changing configuration of the test system, the spatial temperature non-uniformity of the black body of the test system can be improved to the level when the condition (1) is fulfilled for all commercially available surveillance thermal imagers.

As stated earlier, a commercially available DT 1500 from Inframet [9] was used to carry out the experiments. However, the experiments can be repeated using test equipment from any manufacturer. Next, there are no logical reasons that the observed positive effects of changing configuration should not be valid for equipment from other manufacturers and using other high sensitivity cooled staring thermal imagers. Therefore, we claim that the presented earlier test results are valid for test systems from any manufacturer. Next, the proposed change of system configuration can be implemented by any manufacturer of equipment for testing thermal imagers practically without any significant costs.

5. Conclusions

On the basis of the presented earlier theoretical analysis and experimental results we can conclude that by changing configuration of typical systems for testing thermal imagers we can improve significantly both temporal temperature stability and spatial temperature uniformity of the black body used in the test system. It can be estimated that when using vertical configuration it is possible to achieve temporal temperature stability at the level ±1 mK and temperature spatial uniformity below 3 mK. In this simple way, by changing system configuration, we can achieve such situation when typical commercially available test systems can be used for testing even the most sensitive staring thermal imagers available on the market.

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