

## New method for two-point nonuniformity correction of microbolometer detectors

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### 1. Introduction

In this paper, the new method of two-point nonuniformity correction of microbolometer detectors is presented. Microbolometer detectors are commonly used in thermal cameras thanks to small dimensions, relatively low price and no requirement for cooling. However, there is a common problem of detector non-uniformity, due to very high thermal sensitivity of the microbolometer structure. Thermograms obtained directly from a detector, without any correction, are almost unusable.

The influence of microbolometer detector housing temperature variations results in the appearance of false temperature gradients in thermograms. This phenomenon causes improper temperature measurement. An example of above mentioned temperature gradient (visible in the background) is shown in Fig. 1 (b), while the corrected thermogram is shown in Fig. 1 (a). Markers in those thermograms display the temperature values, in °C. One may notice that the temperature readout error prior to correction peaks at about 16,6°C in this particular example.

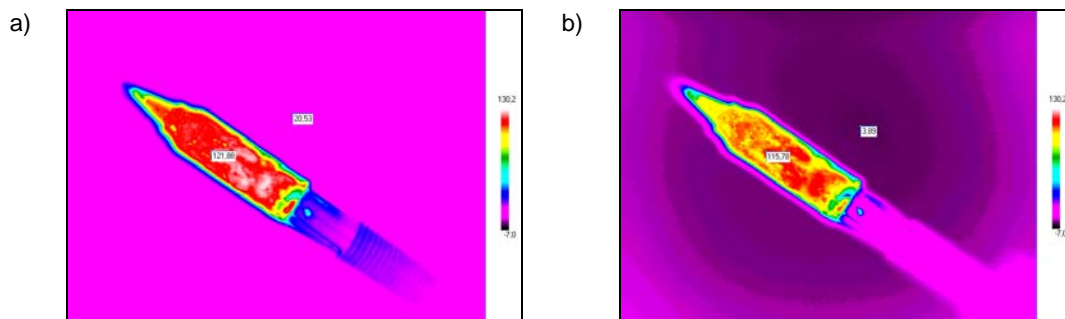


Fig. 1. a) corrected thermogram, b) thermogram prior to nonuniformity correction

### 2. Nonuniformity correction – traditional one-point approach

Under the assumption that the characteristic of a single microbolometer can be described by a linear equation (1), there are two parameters that can be corrected for each microbolometer – offset and gain. [1]

$$Y(T_{i,j}) = g_{i,j} \cdot \phi + o_{i,j} \quad (1)$$

where:

$Y(T_{i,j})$  is the response of a microbolometer on position  $i,j$  in a detector to an IR radiation flux  $\phi$  corresponding to the temperature  $T_{i,j}$ ,

$g_{i,j}$  is the gain of this microbolometer,

$o_{i,j}$  is the offset.

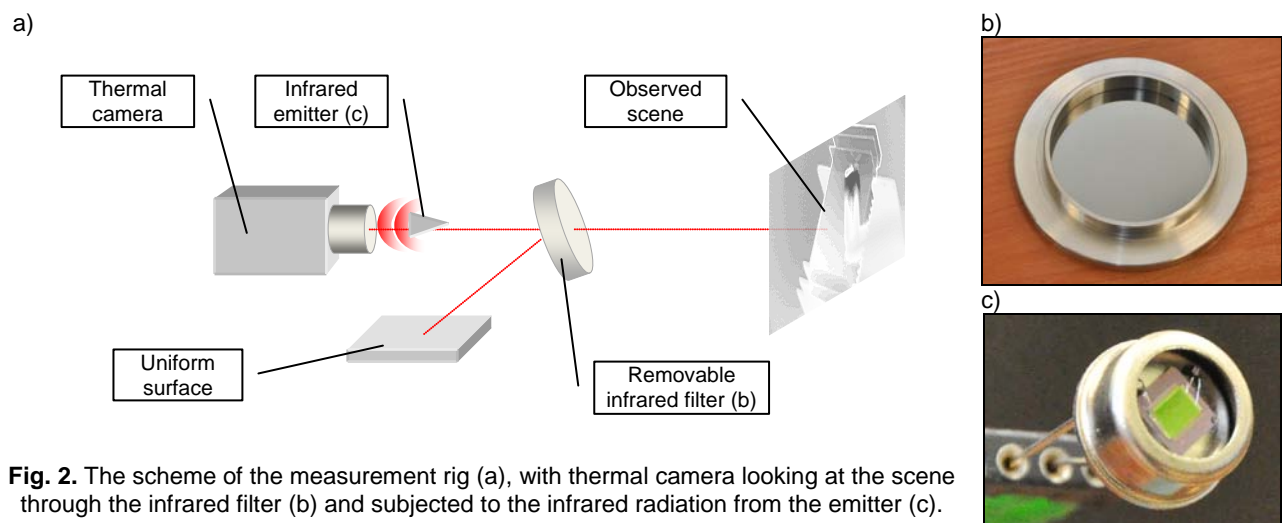
It is essential to provide the compensation for detector nonuniformity during the measurements carried out with a thermal camera. The commonly used approach relies on the mechanical shutter, which is periodically introduced in front of the detector surface. This method is called one-point NUC (*NonUniformity Correction*), because it can correct only the offset

parameter ( $\sigma_{ij}$ ). The drawback of this method is that every minute shutter disturbs the thermal observation resulting in periodically “frozen” image for one to two seconds.

It is assumed that all microbolometers have gain values corrected at the factory, and there is no need to repeat this correction. However, in [2], it was shown that in practice the gain parameter also changes with time, partly because of the ageing of microbolometers, but also for example due to the ubiquitous dust that may be present on the surface of infrared lens or detector.

### 3. Nonuniformity correction – the proposed two-point method

The proposed method combines both the offset and gain nonuniformity correction. Its principle is based on using a removable infrared filter for offset correction, and an infrared emitter for gain correction. The filter has to be semi-transparent for infrared radiation. The IR emitter is an additional source of infrared radiation, which stays out-of-focus and provides the excitation to the detector in parallel with the radiation of observed scene. The main advantage of proposed method is the lack of interruptions of thermal observation during the correction. The scheme of the measurement rig is shown below.



**Fig. 2.** The scheme of the measurement rig (a), with thermal camera looking at the scene through the infrared filter (b) and subjected to the infrared radiation from the emitter (c).

#### 3.1 Gain non-uniformity

The proposed gain non-uniformity correction approach is based on using an infrared emitter. Its purpose is to subject the microbolometer matrix inside the camera to an additional infrared radiation in parallel with the radiation coming from the observed scene. In case of experiments presented in this paper, this element is localized in front of the lens, close to its surface, hence it remains invisible for the camera until turned on (stays out of focus), as shown in Fig. 2. In the final applications, however, it is planned to localize it inside the camera, but not in the optical path of detector-lens-scene.

The emitter radiation may be modulated with the sinusoidal or square function with frequency of about 20 to 25 Hz. This is the highest framerate that typical microbolometer camera can record, while the observed scenes rarely contain such frequency components. The response of the detector solely to the IR emitter excitation may be calculated using frequency analysis (e.g. FFT), and it contains the information about the gain non-uniformity of this detector. This method enables a thermal camera to perform a live gain correction without using a shutter. It is possible to use a simpler approach, which assumes capturing two consecutive frames in the shortest possible time period – the first one with the additional radiation, the second one without. The difference between those frames contains the gain non-uniformity information. In practice, in both cases it is required to provide the compensation for the uneven illumination of the microbolometer matrix by the emitter.

The frequency component of the emitter may be eventually removed from the thermal image delivered to the camera screen. The detailed description of the proposed method for gain-non uniformity correction is provided in the patent application [3].

### 3.2 Offset non-uniformity

The proposed method for the offset non-uniformity correction relies on a removable infrared filter, which is periodically introduced in between the camera lens and observed scene (similarly as a shutter in traditional NUC solutions is inserted between the lens and detector). Authors found out that inclining the filter protects against lens reflections in the filter surface. Knowing the filter transmittance for infrared radiation, it is possible to calculate the microbolometer matrix offset map, and use it to perform offset correction, taking into account the previously calculated gain nonuniformity information. Therefore the proposed method is a two-point correction, and it is believed to be more accurate than the one-point approach. During the instantaneous filter usage it is possible to compensate for its transmission to deliver the live thermal image to the camera screen. The filter with a uniform transmittance factor  $\tau_f$  is an additional source of infrared radiation with emissivity  $\varepsilon_f$ , according to the Kirchhoff's law:

$$\varepsilon_f = 1 - \tau_f - \rho_f. \quad (2)$$

It is required to acquire two thermograms (with the shortest possible time delay) – before introduction of infrared filter, and directly after inserting it in front of the microbolometer detector. Between those acquisitions the camera and scene is assumed to be stationary. Before filter introduction the readout of microbolometers may be described by the equation (1), assuming the linear character of response to a narrow range of scene temperatures. In case of the second thermogram (with the filter), the response  $Y^*$  of microbolometers may be described by the following equation:

$$Y^*(T_{i,j}) = g_{i,j} \cdot [\tau_f \cdot \phi(T_{i,j}) + \phi(T_f) \cdot (1 - \tau_f)] + o_{i,j} \quad (3)$$

where:

$Y^*(T_{i,j})$  is the response of a microbolometer on position  $ij$  in a detector to an IR radiation flux  $\Phi$  corresponding to the temperature  $T_{i,j}$ , after introducing the filter,

$\tau_f$  is the transmittance of this filter,

$\phi(T_f)$  stands for the IR radiation flux corresponding to the filter temperature.

The solution of (1) and (3) for  $\phi(T_{i,j})$  and  $o_{i,j}$  is given by (4) and (5), respectively [4]:

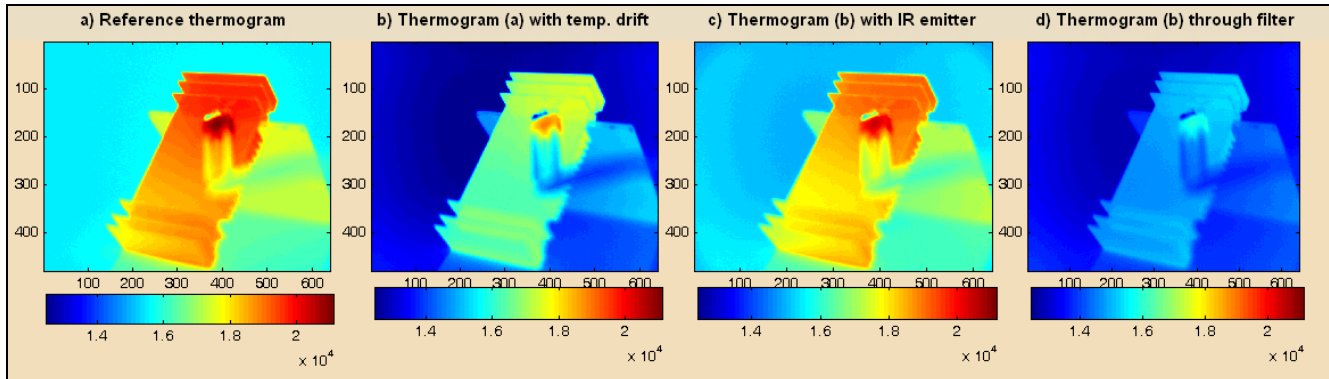
$$\phi(T_{i,j}) = \frac{Y_{i,j} - Y^*_{i,j}}{g_{i,j} \cdot (1 - \tau_f)} + \phi(T_f) \quad (4)$$

$$o_{i,j} = \frac{Y^*_{i,j} - y_{i,j} \cdot \tau_f}{1 - \tau_f} - \phi(T_f) \cdot g_{i,j} \quad (5)$$

The flux of scene radiation, irrespective of the microbolometer temperature drift, is given by (4). Applying (4) for all microbolometers in the matrix, one can perform the two-point non uniformity correction. In result, the real thermogram of observed scene may be obtained, without measurement errors introduced by the temperature drift phenomenon, that may be calculated using (5).

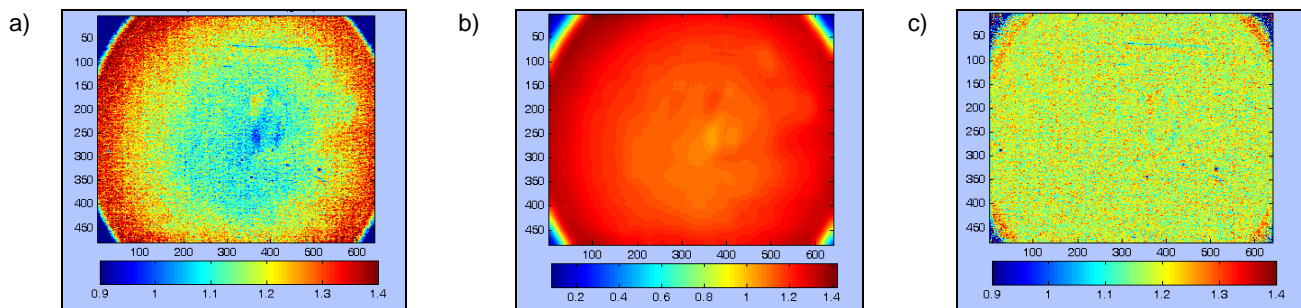
### 4. Correction results

Fig. 3 (a) presents the reference thermogram, which is not burdened with any measurement errors. If the non-uniformity correction is abandoned, the false temperature gradients appear due to the thermal drift phenomenon. With time, the measurement error arises, what is shown in Fig. 3 (b) – scene temperatures remained unchanged, but microbolometer readouts are different than in case of Fig. 3 (a). Let's suppose that at this point one wants to perform the two point non-uniformity method using the proposed approach. The first required thermogram is Fig. 3 (b), as seen by the camera. Instantaneously one should introduce the infrared filter (as shown in Fig. 2) and record the second thermogram - Fig. 3 (d). After the filter is removed, the infrared emitter is turned on, and third thermogram is acquired - Fig. 3 (c). It is important to keep the lowest possible time delay between recording those thermograms to ensure that scene content and camera position does not change in between. Alternatively it is possible to extract thermogram Fig. 3 (c) using frequency analysis, when infrared emitter pulsates with a given frequency. In this case the camera is not required to be stationary.



**Fig. 3.** Input thermograms: **a)** reference thermogram not burdened with the temperature drift, **b)** thermogram (a) burdened with the temperature drift, **c)** thermogram (b) with additional radiation from IR emitter, **d)** thermogram (b) recorded through the infrared filter

Having these thermograms recorded, one should follow the procedure described in paragraphs 3.1 and 3.2 – in particular apply equation (4) in a pixel-by-pixel manner. Fig. 4 (a) presents the image of measured gain non-uniformity distribution. It contains both the low and the high frequency component. The former appears due to uneven matrix illumination from infrared emitter, and may be extracted by applying the low-pass filtration - Fig. 4 (b). The high frequency component stands for the real gain non-uniformity, and may be calculated by subtracting Fig. 4 (b) from Fig. 4 (a) – the result is visible in Fig. 4 (c). One may notice the issue of vignetting, which is to be addressed in future works.



**Fig. 4.** **a)** Measured gain non-uniformity distribution burdened with uneven matrix illumination by infrared emitter, **b)** the image of matrix illumination intensity distribution by infrared emitter obtained by low-pass filtration of (a), **c)** measured gain non-uniformity distribution across the microbolometer matrix, with removed low frequency component (b)

The main source of measurement errors lies in the thermal drift phenomenon, which causes the microbolometer offset shifts. Using (5), authors calculated the image of the offset non-uniformity - Fig. 5 (a). There are edge artifacts in the image, possibly because of the sharpening algorithms built into the thermal camera applied for the experiment. In the final applications, however, raw thermograms are to be used instead of pre-processed ones and therefore such problems shouldn't appear. If gain is assumed to be equal for all microbolometers, the non-uniformity correction becomes one-point – the result of such a correction is shown in Fig. 5 (b). The effect of two-point NUC (including both offset and gain non-uniformity) is shown in Fig. 5 (c). If one observes the correction results (Fig. 5 b, c) similarity to the reference thermogram shown in Fig. 4 (a) is clearly visible. It proves that proposed method works correctly. In case of quantitative analysis of this particular experiment, the mean measurement error introduced by the thermal drift phenomenon was reduced by about 92% with the use of proposed correction method. This value was calculated using formula (7) as the percentage reduction of mean square error value (MSE) given by (6).

$$MSE_X = \sqrt{\frac{\sum_{i=1}^M \sum_{j=1}^N (Y^{REF}(T_{i,j}) - X)^2}{M \cdot N}} \quad (6)$$

where:

$M$  – number of columns in a microbolometer matrix,

$N$  – number of rows in a microbolometer matrix,

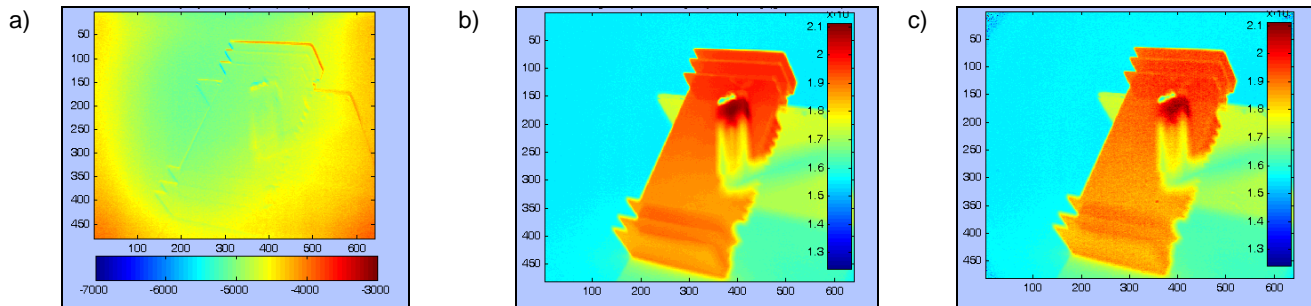
$Y^{REF}(T_{i,j})$  – the reference response of a microbolometer in a position  $ij$  in a detector (not burdened with the thermal drift) to an IR radiation flux  $\Phi$  corresponding to the temperature  $T_{i,j}$ ,

$X$  stands for:

$Y(T_{i,j})$  – the response of a microbolometer in a position  $ij$  in a detector to an IR radiation flux  $\Phi$  corresponding to the temperature  $T_{i,j}$ , burdened with the thermal drift – for calculating MSE value introduced by the thermal drift, or

$\phi(T_{i,j})$  – for calculating MSE value after the correction with proposed method.

$$EFF = \frac{MSE_{Y(T_{i,j})} - MSE_{\phi(T_{i,j})}}{MSE_{Y(T_{i,j})}} \cdot 100\% \quad (7)$$



**Fig. 5. a)** calculated image of the offset parameter nonuniformity across the microbolometer matrix, **b)** the result of one-point nonuniformity correction with the proposed method, **c)** the result of two-point nonuniformity correction with the proposed method

## 5. Conclusions

Authors managed to perform the two-point nonuniformity correction without interruption of the thermal observation, what was not possible in the case of the traditional shutter-based method. Knowing the transmittance of the filter (in case of this research  $\tau_f = 0,48$ ), camera may compensate for it when displaying thermogram, so that the introduction of a filter may be invisible for the user. Also the IR emitter signal may be eventually filtered out from displayed thermograms.

Proposed method was proven to be useful and efficient for applications such as shutterless measurement thermal cameras. In the final applications both the infrared filter and emitter are to be built into the camera, and operate without any user input. It is planned to replace the removable filter with tunable one, to simplify the construction and remove mechanical motor otherwise necessary for removing and inserting the filter.

The proposed method is under permanent development. In case of the research presented in this paper, the two-point correction quality was not any better than one-point approach. However, it is believed that the two-point correction should show its supremacy in case of thermograms with high temperature span. In future works, authors will maximize the correction efficiency by introducing thermograms averaging and motion estimation techniques.

## REFERENCES

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