PAPER • OPEN ACCESS

Calibration of thermal imaging systems based on matrix IR photodetectors

To cite this article: M N Petrov et al 2019 J. Phys.: Conf. Ser. 1352 012036

View the article online for updates and enhancements.

You may also like

- Analysis of Gas Permeation Phenomena in a PEM Water Electrolyzer Operated at High Pressure and High Current Density M. Bernt, J. Schröter, M. Möckl et al.
- THE RADIO ACTIVITY-ROTATION RELATION OF ULTRACOOL DWARFS M. McLean, E. Berger and A. Reiners
- <u>The growth of epitaxial graphene on SiC</u> and its metal intercalation: a review Dong Yang, Fei Ma, Xianglong Bian et al.





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 3.23.101.60 on 07/05/2024 at 18:49

IOP Publishing

Calibration of thermal imaging systems based on matrix IR photodetectors

M N Petrov¹, P S Sobolev² and B V Cherniak²

¹ Yaroslav-the-Wise Novgorod State University, ul. B. St. Peterburgskaya, 41
173003, Veliky Novgorod, Russia
² JSC Special Design Office "Omega", ul. Sashy Ustinova, 41
173003, Veliky Novgorod, Russia

E-mail: Mikhail.Petrov@novsu.ru

Abstract. The article presents a set of calibration techniques for thermal imaging systems calibration. The proposed algorithms allow high-precision calibration of the IR photodetector with finding and subsequent correction of the entire spectrum of defective pixels: by noise, amplitude and sensitivity. Part of the work is devoted to the development of methods for correcting the influence of ambient temperature on the optical system of a thermal imaging channel, which helps to prevent the effect of super saturation of the IR image pixels.

1. Introduction

The aim of this work is to develop a set of methods for calibrating optical thermal imaging systems based on matrix IR photodetectors. Here are two groups of methods:

- Calibration of IR photodetectors by correcting the uneven sensitivity of individual pixels using the three-point correction algorithm;
- Correction of the influence of ambient temperature on the optical system of thermal imaging channel, which is caused by temperature changes in the properties of the optics, namely the properties of the objective lenses.

2. Matrix IR calibration method based on three-point correction

In this work, the IR system produced by South Korea company "i3Systems" was used as an IR photodetector. This photodetector is made on the basis of the semiconductor material InSb and operates in medium IR range from 3 to 5 microns.

Photodetector resolution is 640×512 pixels, with a pixel size of 15 microns. The working temperature range for it is from -40 to +60 ° C. Since the curve of the IR photodetector brightness versus temperature is non-linear, the working temperature range is divided into five sub-ranges so that each of them is close to linear dependance:

- (-40 ÷ -20)°C;
- $(-20 \div 0)^{\circ}C;$
- (0 ÷ 20)°C;
- (20 ÷ 40)°C:
- $(40 \div 60)^{\circ}$ C.

The following algorithm for the calibration of the IR matrix is performed for each of the marked temperature ranges. Further, as an example, we consider the sequence of actions for the temperature sub-range $(40 \div 60)^{\circ}$ C.

To perform three-point correction, it is necessary to record N frames for each of the three sub-range temperatures. The setting of the corresponding temperature is carried out with the help of a test object implemented on the basis of absolutely black body (ABB) source.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

In the process of performing calculations on the basis of N frames, a matrix is formed consisting of N columns whose length (number of rows) corresponds to the frame size (*KADR* is a number of pixels in the frame):

$KADR = X \times Y = 640 \times 512 = 327680.$

Using larger number of frames provides higher accuracy of calculations, since some defective pixels appear only after a sufficiently long period of time. Such pixels are thrown out and replaced by pixels obtained by finding the average of the four neighboring pixels. In this work, the optimal number of frames N = 200 is chosen experimentally.

2.1. IR photodetector calibration algorithm

Step 1. Performing rejection of noisy pixels.

These are pixels whose amplitude one or more times over N frames is noticeably different from the amplitude of the neighboring pixels (found by linear approximation of the histograms of pixel distribution by amplitude after ranking). To identify noisy pixels, you usually calculate the average value of each pixel over N frames [1, 5]. As a result, the pixels in which the defect does not appear permanently are not rejected. As it turned out in practice, this is not entirely correct, since the flickering of such pixels is quite clearly visible with an eye. In this paper, histograms of pixel distributions at three temperatures (figure 1) are built to identify noisy pixels. This allows you to use the difference between the maximum and minimum pixel values over N frames to reject pixels whose noise is noticeably different from other pixels. This procedure allows you to identify and correct the pixels (replacing the values obtained by interpolation of four neighboring pixels), in which the defect appeared at least once in N frames.

Figure 1 shows the histograms of pixels distribution by the noise amplitude at three temperatures in one of the temperature sub-ranges.



Figure 1. Distribution histograms of pixels of matrix photodetector by noise amplitude for three temperatures: -40° C; - · - 50°C; ---- 60°C.

Part of the graph (from 0% to 99.84%) is uninformative, since it has a linear appearance. In this part of the graph, pixels have a noise amplitude within the normal range. Nonlinearity appears for pixels located in the range of (99.84 \div 100)%. This is part of the "noisy" pixels that will be rejected, and later replaced by an interpolation procedure.

Step 2. Performing pixels rejection by amplitude.

Unlike noisy pixels, the amplitude of some pixels can be much larger than the amplitude of nearby pixels and often does not change with time and with temperature. Such pixels appear as white or black dots in the

image, and they must be replaced by interpolated pixels. Figure 2 shows the histograms of pixels distribution by amplitude for three temperatures: 40° C, 50° C and 60° C.



Figure 2. Distribution histograms of pixels of matrix photodetector by amplitude for three temperatures: -40° C; - · - 50°C; ---- 60°C.

Here, also, the linear part of the graph (from 0% to 99.78%) is of no interest, since the amplitude of these pixels non-significantly differs from the nearby ones. The dependence presented on the graph is non-linear after the value of 99.78%. This includes the part of the pixels that will be replaced by interpolating four adjacent pixels.



Figure 3. Histograms of pixels differences distribution by sensitivity for two temperature ranges: $-(40\div50)^{\circ}$ C and $-(50\div60)^{\circ}$ C.

Step 3. Performing pixels rejection by sensitivity.

Using IR images for three temperatures, we build two histograms of the difference in pixel amplitudes: between images with low (40°C) and medium (50°C) temperatures, medium (50°C) and high (60°C) temperatures (figure 3). In contrast to the correction for two temperatures, this method allows to identify pixels that are characterized by a nonlinear change in amplitude with increasing temperature. So, their amplitude can vary linearly in the temperature range $(40 \div 50)^{\circ}$ C and non-linearly in the temperature range $(50 \div 60)^{\circ}$ C. Such non-linear pixels are very noticeable in the image as white dots, which reduces the image quality. If we take the difference between the amplitudes of the pixels at two temperatures (two-point correction), then these pixels may not be seen during calibration.

When calculating the sensitivity it is necessary to take into account some points. This is due to the choice of exposure time which must ensure maximum sensitivity. However, it should not be forgotten that when using long exposure time, the image can become super saturated. In addition, when choosing the exposure time it is necessary to take into account the possibility of using a lens. So, if the calibration is made from the installation object without a lens, then the exposure time should be chosen a little less, since the image obtained using the lens can become super saturated. The exposure time is determined by the selection method for each sub-range of temperatures and individually for each matrix photodetector.

Figure 4 shows the sensitivity of matrix photodetector of "i3System" firm in the center of the image (line by line) with selected accumulation time in the temperature range $(40 \div 60)^{\circ}$ C.



Figure 4. Sensitivity of IR "i3System" matrix photodetector (line by line).

The results presented in figure 4 indicate the choice of the optimal accumulation time for which no oversaturation effect is observed (there is no cut of the graph tops of the matrix photodetector sensitivity). As additional confirmation of usage of the optimal accumulation time can serve the image shown in figure 5, where there are no vertical stripes of white color characteristic for the super saturation mode.



Figure 5. Confirmation of the choice of the optimal accumulation time - the image at the noise level (illumination).

IOP Publishing

Step 4. Calculation of the correction coefficient.

As already noted, the calibration of matrix photodetector is performed using a test object, which is absolutely black body with a constant temperature. On this basis, it follows that each pixel of the image must be reproduced with the same brightness (have the same amplitude). In fact, this is not the case, which is related to the quality of manufacturing the crystal of the photosensitive element of the matrix photodetector. Therefore, during the calibration process, it is necessary to calculate the correction coefficient k, which will align the amplitude of the pixels during processing. This coefficient, normalized to one, is calculated by the following formula:

$$k_{ij} = \frac{S_{ij}^{(hot)} - S_{ij}^{(cold)}}{T_{hot} - T_{cold}},$$

where $S_{ij}^{(hot)}$ and $S_{ij}^{(hot)}$ are values of pixel responses at hot T_{hot} and cold T_{cold} temperatures, respectively.

Figure 6 shows the matrix of equalizing coefficients, when superimposed on the IR image, the pixels are aligned with the amplitude of the matrix photodetector.



Figure 6. The matrix of equalization coefficients.

Figure 6 shows the darkening of the equalizing coefficients from the center to the corners of the image. This is due to the fact that at the input of the photodetector there is an aperture and the direct flow falls mainly on the central part of the image, the remaining areas are highlighted by a weaker indirect flow. As a result it is necessary to increase the equalizing coefficients from the center to the corners of the image.

Step 5. Test for presence of clusters of defective pixels.

The final stage of calibration is the test for presence of clusters of defective pixels, bringing into existence of large insensitive areas. Figure 7 shows the image with all rejected pixels during the calibration process. It can be seen that there are no clusters of rejected pixels in it, therefore, insensitive areas are absent.



Figure 7. Pixels rejected during calibration.

IOP Publishing

3. Correction of the temperature effect on the optical system of the IR camera

Along with the change in the characteristics of the photodetectors that form the IR photoelectric receiver, the change in temperature also effects the optical system of a camera. This is due to the fact that the lens of the camera is made of a semiconductor material (germanium or silicon), which is extremely sensitive to temperature.

To investigate the effect of temperature on the characteristics of the optical system of an IR camera, it was placed in a climate chamber. The methodology of the experiment is described in detail in [2], therefore, only the experimental results are considered here.

In the course of the experiments, it was found that with change in the temperature of the climate chamber for every 10°C, the constant component of the measured signal (pixel amplitude) from the source of the ABB changes by (10-20)%. With increasing temperature, the constant component increases, and with decreasing - decreases.

Figure 8 shows fragments of the output signal (pixel amplitude) with matrix photodetector (line by line), measured at a constant temperature of the source of blackbody (T=30°C), but different temperatures in the climatic chamber: 10° C (lower graph) and 30° C (upper graph). It can be seen from the graph that as the temperature in the climate chamber increases from 10° C to 30° C, the constant component of the output signal from the matrix photodetector increased by 16%.



Figure 8. Output signal with matrix photodetector (a fragment of the frame, taken line by line) for two temperatures: 10°C (lower graph) and 30°C (upper graph).

3.1. Algorithm for correcting the effect of temperature on the characteristics of the lens of an IR camera lens

Step 1. For each matrix photodetector there are maximum and minimum levels of the output signal.

We measure the maximum signal level (U_{max}) with a matrix photodetector at a given maximum temperature in the climatic chamber at a certain temperature of the radiation source ABB.

Step.2. Without changing the temperature of the ABB radiation source, we measure the level of the U_{room} signal from the matrix photodetector at room temperature.

Step.3. We calculate the signal level U_{lim} above which there will be a super saturation of pixels in the IR image:

$$U_{\text{lim}} = U_{\text{max}} - U_{\text{room}}.$$

Step.4. We select the exposure time, taking into account the U_{lim} signal level defined above.

The proposed algorithm is used when calibrating a thermal imaging camera to prevent the effect of super saturation of the IR image pixels. The result of the manifestation of this effect may be the appearance of fragments in the image with constant contrast, which leads to loss of information. This creates problems with the correct identification of objects of interest, which is unacceptable in extreme conditions.

4. Conclusion

The proposed algorithms allow the calibration of the IR matrix photodetector with the finding of the entire spectrum of defective pixels: noise, amplitude and sensitivity with high accuracy.

The second part of the work, devoted to the development of a technique for correcting the influence of the ambient temperature on the optical system of thermal imaging channel, prevents the effect of oversaturation of pixels in IR image, which leads to fragments with constant contrast appearing on the image, which leads to information loss.

As a result of calibration, it is possible to achieve high quality and uniform pixel uniformity of the thermal image.

References

- [1] Solina N I and Kravets O I 2004 Sensitivity calibration and correction of geometric noise in thermal imaging by the method of two-point correction. International collected works 15 (Voronezh, "Scientific book") p 140
- [2] Sobolev P S, Chernyak B V and Petrov M N 2019 Correction of the influence of ambient temperature on the optical system of thermal imaging channel. *Vestnik NovSU* **4** (114)
- [3] Budzier H and Gerlach G 2015 Calibration of infrared cameras with microbolometers *Proc. Int. AMA Conferences 2015 – SENSOR 2015 and IRS2 2015* (Nuremberg) 889–894
- [4] Tempelhahn A, Budzier H, Krause V and Gerlach G 2014 Development of a shutterless calibration process for microbolometer-based infrared measurement systems (Solid-State Electronics Laboratory, Technische Universität Dresden, Dresden, Germany) p 10
- [5] Borzov S M, Kozik V I and Potaturkin O I 2009 Correction of infrared images on the base of real-time statistical data processing *Journal of Instrument Engineering* Vol **52 6** 11–17