A Nonuniformity Correction Method Based on Gradient Scene Calibration

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Abstract. The nonuniformity of infrared focal plane array (IRFPA) seriously affects the image quality and the measurement accuracy of the infrared imaging system. The two-point nonuniformity correction (NUC) method based on blackbody calibration performs a less than very satisfactory result to correct the sky scene with gradient gray distribution. Aiming at this problem, a new NUC method based on gradient scene calibration is proposed. First, the correction models are deduced in theory with the reference of the blackbody and the gradient scene. Then the pure sky images at the two different pitch angles are used as two reference temperature points to obtain the gain and offset coefficients by two-point correction. Next, two correction coefficients are filtered to remove residual noise. Finally, an outfield experiment with the proof-of-concept camera is performed. Experimental results show that the signal-to-noise ratio (SNR) of the point target image corrected by the proposed method is increased from 5.56 to 9.84 compared with the blackbody calibration-based NUC. And it has the preference of low complexity and easy implementation in the real-time system.

1. Introduction
Infrared focal plane array (IRFPA) technology is widely applied to the thermal imaging system. IRFPA detector has the features of high sensitivity and high resolution compared with the scanning imaging system. However, the output response of all the pixels in IRFPA detector is inconsistent even for the uniform radiation, which is known as the nonuniformity, due to defective doping process, material mask and optical system error [1,2]. The nonuniformity usually causes the fixed-pattern noise (FPN) and the random noise which severely decrease the image quality and the accuracy of measurement system. To solve the problem of the nonuniformity of IRFPA detector, domestic and foreign researchers have proposed two kinds of NUC methods: NUC based on the blackbody calibration and the scene methods.

Scene-based NUC method obtains the correction coefficients of IRFPA detector by iteratively calculating the scene information of the image sequence. The commonly used scene-based NUC methods mainly include temporal high-pass filtering method [3], constant statistics method [4], neural network method [5] and Kalman filter method [6]. The precondition of the scene-based NUC is that the gray level of the scene in the image sequence should be uniform, and the target's static time in the scene should not be too long. If the precondition is violated, the target will be regarded as a part of nonuniform noise, and the ghost will be generated in the corrected image. At the same time, the complexity of the algorithm is relatively high, and the convergence speed needs to be improved [7].

Aimed at the principle of nonuniformity, the blackbody calibration-based NUC method corrects the response of each detector in IRFPA at different known temperatures, so that all pixels output the same gray level. Calibration method is widely used, especially the two-point correction algorithm. The two-
point NUC method can be realized only by one multiplication and addition operation. For the airborne infrared point target detection system, the ambient temperature is usually from -50 to -30 degrees centigrade, and the optical system will inevitably undergo weak deformation. The calibration coefficient of the blackbody calibration is difficult to meet the high precision requirements of the airborne detection system [8].

Based on two-point NUC method, a NUC method based on gradient scene calibration is proposed to achieve the high-precision calibration of infrared detector for the sky scene with gradient gray distribution encountered by the airborne point target detection system.

2. NUC based on gradient scene calibration

2.1 Two-point NUC Model

Two-point NUC is a mature correction algorithm, which widely used in actual projects. Usually, an IRFPA is characterized by a linear model during a short period of time. Then, for the (i, j) pixel, the output response of IRFPA has the following expression:

\[ X_{ij}(\Phi) = \mu_{ij} \Phi + v_{ij} \]  

(1)

where \( \mu_{ij} \) and \( v_{ij} \) are respectively the gain and offset coefficients of pixel (i, j). \( \Phi \) is the infrared radial flux, and \( X_{ij}(\Phi) \) is the response value of pixel (i, j).

Two-point NUC employs the blackbody at two different known temperatures around the operation point so as to estimate gain and offset coefficients of the linear model of nonuniformity. The corrected response value can be expressed through the following equation:

\[ Y_{ij} = K_{ij}X_{ij}(\Phi) + B_{ij} \]  

(2)

where \( K_{ij} \) and \( B_{ij} \) are called corrected gain and offset coefficients of the detector. The gain and offset coefficients are obtained:

\[ K_{ij} = \frac{Y(\Phi_y) - Y(\Phi_l)}{X_{ij}(\Phi_y) - X_{ij}(\Phi_l)} \]  

(3)

\[ B_{ij} = \frac{Y(\Phi_y)X_{ij}(\Phi_l) - Y(\Phi_l)X_{ij}(\Phi_y)}{X_{ij}(\Phi_y) - X_{ij}(\Phi_l)} \]  

(4)

where \( X_{ij}(\Phi_l) \) is the output value at low temperature of the blackbody, and \( X_{ij}(\Phi_h) \) is the output value at high temperature. \( Y(\Phi_y) \) and \( Y(\Phi_y) \) are average response values at high and low temperature respectively.

2.2 Gradient Scene Calibration Model

For the pure cloudless sky scene, the sky radiation temperature decreases stepwise from low altitude to high altitude, which is so-called gradient sky scene. The radiation flux of standard blackbody is identical in the direction of i and j, while the radiation flux of gradient sky scene decreases gradually with the increase of pitch angle. It can only be approximated that the radiation flux of gradient sky scene is identical in the direction of j and decreasing gradually in the direction of i. For simplicity of calculation, two standard blackbody images are assumed to be \( I_1 \) and \( I_2 \), and radiation fluxes are \( \Phi_1 \) and \( \Phi_2 \), respectively. The radiation flux of gradient scene is \( \Phi_{z,i,j} \), the image of gradient scene is \( I_{z,i,j} \), and the corresponding correction coefficients are \( K'_{ij} \) and \( B'_{ij} \), respectively. Thus we have

\[ \Phi_{z,i,j} = \Phi_2 - \Delta \Phi_i \]  

(5)
The blackbody image $I_z$ in two-point correction is replaced by $I'_z$. There are:

$$K'_ij I_{k,i,j} + B_{ij} = \overline{I'}_1$$  \hspace{1cm} (6)

$$K'_ij I'_{2,i,j} + B_{ij} = \overline{I'}_2$$  \hspace{1cm} (7)

where $\overline{I'}_2$ is the mean of the image $I'_2$. According to (7), the correction coefficient $K'_{ij}$ can be obtained:

$$K'_{ij} = \frac{\overline{I'}_2 - \overline{I'}}{I'_{z,i,j} - I_{z,i,j}}$$

$$= \frac{1}{MN} \sum_i \sum_k \mu_m (\Phi_2 - \Phi_1 - \Delta \Phi_s) - \mu_j (\Phi_2 - \Phi_1 - \Delta \Phi_f)$$

$$= \frac{1}{MN} \sum_i \sum_k \mu_m (\Phi_2 - \Phi_1 - \Delta \Phi_f - \Delta \Phi_s + \Delta \Phi_f) - \mu_j (\Phi_2 - \Phi_1 - \Delta \Phi_f)$$

$$= \frac{1}{\mu_i} \sum_i \sum_k \mu_m (\Delta \Phi_f - \Delta \Phi_s) - \mu_j (\Phi_2 - \Phi_1 - \Delta \Phi_f)$$

$$= \frac{1}{\mu_i} \sum_i \sum_k \mu_m (\Delta \Phi_f - \Delta \Phi_s) - \mu_j (\Phi_2 - \Phi_1 - \Delta \Phi_f)$$

$$= K_{ij} + K'_{ij} \cdot \sum_{k} (\Delta \Phi_f - \Delta \Phi_s)$$

$$= \sum_{k} (\Delta \Phi_f - \Delta \Phi_s)$$

To simplify the formula, $\gamma_i$ is introduced and expressed as follows:

$$\gamma_i = \frac{\sum_{k} (\Delta \Phi_f - \Delta \Phi_s)}{\mu (\Phi_2 - \Phi_1 - \Delta \Phi_f)}$$  \hspace{1cm} (9)

Therefore, (8) can be simplified as follows:

$$K'_{ij} = K_{ij} (1 + \gamma_i)$$  \hspace{1cm} (10)

Then the bias coefficient $B'_{ij}$ can be obtained:

$$B'_{ij} = I'_1 - K'_{ij} \cdot I_{z,i,j}$$

$$= \mu \cdot \Phi_i + v - \frac{\mu}{\mu_j} (1 + \gamma_i) (\mu_j \Phi_i + V_{ij})$$

$$= v - \frac{\mu}{\mu_j} V_{ij} - \frac{\mu}{\mu_j} \cdot \gamma_i (\mu_j \Phi_i + V_{ij})$$

$$= B_{ij} - \gamma_i \cdot \frac{\mu (\Phi_i + V_{ij})}{\mu_j}$$

(11)
For the image $I'_2$, the image corrected by standard blackbody is set as $Y'_2$, the image corrected by gradient scene is $Y''_2$, so there are:

$$K'_{i,j}I'_{z,i,j} + B'_{i,j} = Y'_{z,i,j} \tag{12}$$

$$K''_{i,j}I''_{z,i,j} + B''_{i,j} = Y''_{z,i,j} \tag{13}$$

The correction coefficients are substituted into (12) and (13). Thus we have:

$$Y'^*_{z,i,j} = Y'_{z,i,j} - \frac{1}{MN} \sum_{i} \sum_{j} K'_{i,j} \Delta \Phi_{ii} + \bar{\mu} \Delta \Phi_{ij} \tag{14}$$

It can be seen that the second item of (14) is a fixed value, which has no relation with the position coordinate. The third term $\bar{\mu} \Delta \Phi_{ij}$ of the formula can exactly compensate for the radiation flux gradient in (5). Therefore, the derived gain and bias correction coefficients $K'_{i,j}$ and $B'_{i,j}$ are used to correct image $I'_{z,i,j}$ by two-point NUC. The corrected image $Y'^*_{2}$ is a uniform image.

The core of the proposed NUC method based on gradient scene calibration is to replace the uniform blackbody in the two-point NUC algorithm with the pure sky scene. The system adopts the mode of weekly sweep with the fixed pitch angle. The pure cloudless scene at higher pitch angle than the to be corrected temperature point image is selected as the low temperature blackbody of the two-point NUC method, and the pure cloudless scene at a lower pitch angle than the to be corrected temperature point image is selected as a high temperature blackbody. The gain correction coefficient and bias correction coefficient can be obtained by the two-point NUC model in Section A.

FPN in the corrected image will disappear after the above process, but there is still a small amount of isolated noise remaining. The gain and bias coefficients are filtered by 5-neighborhood median filter to eliminate the residual noise.

3. Experimental results
To obtain reliable image resources and verify the effectiveness of the proposed algorithm in this paper, Stirling cooled IRFPA detector system is set up, as illustrated in Fig. 1.

![Figure 1. Experimental equipment](image-url)
gradient scene calibration-based NUC, the nonuniformity has been improved, and the FPN and random noise disappear completely.

Figure 2. Results of NUC, (a) original image, (b) T1 temperature image, (c) T2 temperature image, (d) result of blackbody and (e) result of gradient scene calibration-based NUC.

4. Comparison and analysis
In order to further verify the effectiveness of the proposed algorithm, we successively corrected the non-uniformity of point target images in complex cloud background based on laboratory blackbody and gradient scene calibration. Fig. 3(a) is the original image, and Fig. 3(b) and (c) are the results of blackbody calibration-based and the proposed gradient scene calibration-based NUC respectively, while point targets are marked with red circles. The signal-to-noise ratio (SNR) of the point target in the images are 5.56 and 9.84 respectively. The correction effect of the proposed algorithm is obviously better than that of the blackbody calibration-based method.

Figure 3. Comparison of correction results of the point target image, (a) original image, (b) result of blackbody and (c) result of gradient scene calibration-based NUC.
Table 1. SNR of the point target in the images

| Table Head | SNR          |
|------------|--------------|
|            | Original image | Blackbody calibration | Gradient scene calibration |
| Value      | 1.78         | 5.56                   | 9.84                       |

5. Conclusions

The nonuniformity of the IRFPA seriously reduces the quality of imaging. Moreover, nonuniformity noise will shift with the change of working environment and time. Therefore, the coefficients of NUC must be acquired in real time and real position. In this paper, a new NUC algorithm based on gradient scene calibration is proposed. First, the correction model of gradient scene calibration is deduced. Then the pure sky images at the two different pitch angles are used as two reference temperature points to obtain the gain and offset coefficients by two-point correction. Next, two correction coefficients are filtered to remove residual noise. The experiment has been performed to test the proposed algorithm. Results verify the proposed method has a better performance than the blackbody calibration-based method.

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