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A Novel Non-Uniformity Correction Algorithm Based On Non-Linear Fit

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***Abstract*—**Infrared focal plane arrays (IRFPA) sensors, due to their high sensitivity, high frame frequency and simple structure, have become the most prominently used detectors in military applications. However, they suffer from a common problem called the fixed pattern noise (FPN), which severely degrades image quality and limits the infrared imaging applications. Therefore, it is necessary to perform non-uniformity correction (NUC) on IR image. The algorithms of non-uniformity correction are classified into two main categories, the calibration-based and scene-based algorithms. There exist some shortcomings in both algorithms, hence a novel non-uniformity correction algorithm based on non-linear fit is proposed, which combines the advantages of the two algorithms. Experimental results show that the proposed algorithm acquires a good effect of NUC with a lower non-uniformity ratio.

***Keywords*—**Non-uniformity correction, non-linear fit, two-point correction, temporal Kalman filter.

I. Introduction

INFRARED focal plane arrays (IRFPA) sensors are widely used in a range of military and civilian applications including thermal imaging, night vision, navigation, tracking, surveillance, fire detection, robotics, and so on. Compared with other thermal imaging systems, the infrared focal plane arrays (IRFPA) imaging system has many advantages, such as good reliability, simple structure, high sensitivity and high system operating frame frequency. Despite these advantages, it has intrinsic deficiencies, for example, sensor non-uniformity, which is an essential problem that must be resolved in its practical applications. Therefore, the research of non-uniformity correction (NUC) is very significant. Generally, the algorithms of non-uniformity correction are classified into two main categories: calibration-based and scene-based algorithms. Calibration-based algorithm can be performed by using uniform temperature sources, but it requires briefly obscuring the field-of-view and leads to additional system size and cost; while scene-based approaches are able to utilize the normal scene data when performing non-uniformity correction and therefore do not require the field-of-view to be obscured. The typical calibration-based approaches are two-point and multi-point calibration techniques [1]. These techniques have high correcting accuracy, but they can't suppress the time drift of IRFPA's response effectively. The linear model will cause big errors especially when the range of the temperature changes widely.

The scene-based correction algorithms mainly use an image sequence and depend on motion to provide diversity in the scene temperature. The scene-based non-uniformity correction technology is now one of the main researches focuses in infrared image processing. Many algorithms have been proposed, such as constant-statistical algorithm [2], temporal high-pass filter technique [3], neural-network algorithm [4], Kalman filter algorithm [5], etc. They can effectively overcome the defect of the nonlinear response of the IRFPA sensor and obtain NUC accuracy.

But these algorithms usually require the focused targets to be moving, otherwise the targets will be regarded as background or scene, so as to be diluted or eliminated. Therefore, in order to avoid the rigid requirement and adapt to eliminate the defect of time drift, a novel non-uniformity correction algorithm based on non-linear fit is proposed, which combines the advantages of both calibration-based and scene-based approaches. The defect of non-uniformity can be solved by the novel algorithm effectively. The results demonstrate that the proposed algorithm gives good correction precision.

The rest of the paper is organized as follows. In Section II the algorithm is described and its processing procedure is given. The experiment results are presented in Section III, followed by the discussion and conclusion.

II. Algorithm Description

Suppose the response of each IRFPA unit is stable in the time domain, it can be fitted by a three-order four-parameter polynomial. Then, the parameters are estimated through collecting the responses under four different temperatures. Later, temporal Kalman filtering is used to modify the time drifts of the parameters. Finally, the non-uniformity of the infrared images are corrected via the modified correction parameters.

Suppose the read-output signal of the ij th detector at the n th frame, $Y_{ij}(n)$, then

$$Y_{ij}(n) = A_{ij}T_{ij}^3(n) + B_{ij}T_{ij}^2(n) + C_{ij}T_{ij}(n) + D_{ij} \tag{1}$$

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Step 2: Calculate the parameters of non-linear fit. Substitute $f_1(i,j)$, $f_2(i,j)$, $f_3(i,j)$ and $f_4(i,j)$ into formula (1), respectively,

$$\begin{cases} \overline{f}_1 = A_{ij}(f_1(i,j))^3 + B_{ij}(f_1(i,j))^2 + C_{ij}(f_1(i,j)) + D_{ij} \\ \overline{f}_2 = A_{ij}(f_2(i,j))^3 + B_{ij}(f_2(i,j))^2 + C_{ij}(f_2(i,j)) + D_{ij} \\ \overline{f}_3 = A_{ij}(f_3(i,j))^3 + B_{ij}(f_3(i,j))^2 + C_{ij}(f_3(i,j)) + D_{ij} \\ \overline{f}_4 = A_{ij}(f_4(i,j))^3 + B_{ij}(f_4(i,j))^2 + C_{ij}(f_4(i,j)) + D_{ij} \end{cases} \quad (2)$$

where $\overline{f}_1$, $\overline{f}_2$ $\overline{f}_3$ and $\overline{f}_4$ is the mean gray of image $f_1(i,j)$, $f_2(i,j)$, $f_3(i,j)$ and $f_4(i,j)$, respectively. Solve the equation group (2), then the four parameters can be obtained.

Step 3: Estimate the non-uniformity corrected gray $C_{ij}(n)$ by non-linear fit algorithm for input image. Using the estimated four parameters, we can get

$$C_{ij}(n) = A_{ij} f_{ij}^3(n) + B_{ij} f_{ij}^2(n) + C_{ij} f_{ij}(n) + D_{ij} \quad (3)$$

where $f_{ij}(n)$ is input image, n is the frame number.

Step 4: Modify the corrected gray by temporal Kalman filter. Let $C_{ij}(n)$ be one of the measurements, set up status equation and measurement equation,

$$X_{k+1}(i,j) = \Phi_k(i,j) X_k(i,j) + M_k(i,j) + W_k(i,j) \quad (4)$$

$$Y_k(i,j) = H_k(i,j) X_k(i,j) + V_k(i,j) \quad (5)$$

where $X_k(i,j) = [\alpha_k(i,j), \beta_k(i,j)]^T$, $\Phi_k(i,j) = \begin{bmatrix} a_k & 0 \\ 0 & b_k \end{bmatrix}$, $H_k(i,j) = [1,1]$, $M_k = \begin{bmatrix} 1-a_k & 0 \\ 0 & 1-b_k \end{bmatrix} \hat{X}_0$, $\hat{X}_0 = [C_{ij}(1)\ 0]^T$, $W_k(i,j)$, $V_k(i,j)$ are white noise respectively, their variance are,

$$Q_k(i,j) = \begin{bmatrix} (1-a_k^2)\sigma_{a0}^2 & 0 \\ 0 & (1-b_k^2)\sigma_{b0}^2 \end{bmatrix}, \quad Rk = I\sigma_{vk}^2 .$$

where a_k, b_k can be assigned constant values according to practical applications. If time drift is tiny, a_k and b_k can be assigned to 0.999; if time drift is big, a_k and b_k can be assigned to 0.9.

Moreover, according to experimental experiences, σ_{a0}^2 can be assigned to 0.25, σ_{b0}^2 can be assigned to 0.1, and Rk can be assigned to 0.05.

Via the estimated status by temporal Kalman filter, the modified non-uniformity correction gray $C'_{ij}(n)$ can be estimated.

$$C'_{ij}(n) = \varphi_k(0,0)\alpha_k(i,j) C_{ij}(n) + \varphi_k(0,1)\beta_k(i,j) \quad (6)$$

III. Experimental Results

The novel non-uniformity correction algorithm was tested by practical image sequences. Experimental results show that the algorithm has perfect non-uniformity correction performance. Fig. 1 is some experimental results by using the proposed algorithm. As can be seen in the figures, the algorithm has achieved good effects. Fig. 2 is an example of non-uniformity correction test. It shows the changes of mean, standard deviation and non-uniformity before and after non-uniformity correction. Here non-uniformity(NU) is defined as:

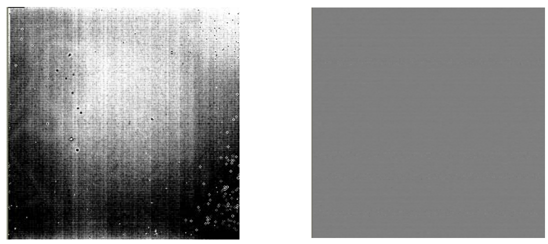
$$\text{NU} = \frac{\sum_{i,j} \left| f_{ij} - \overline{f} \right|}{N\overline{f}} \quad (7)$$

where i and j stands for the row and column respectively, f_{ij} is the gray of pixel (i,j) in image f, N is the total pixel number of image f, $\overline{f}$ is the mean of whole image,

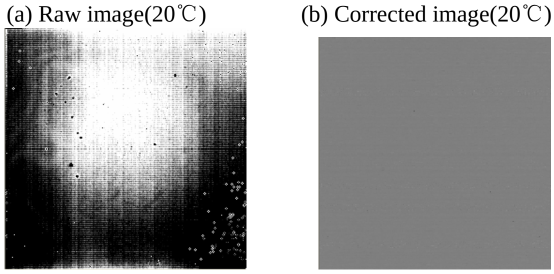
$$\overline{f} = \frac{1}{N} \sum_{i,j} f_{ij}$$

As is seen in Fig. 2, the NU goes down from about 1 percent to about 1.1×10^{-4} after non-uniformity correction, and the NU keeps a lower level after the algorithm converges.

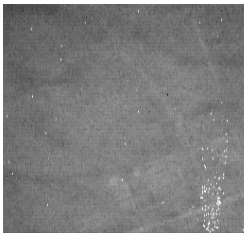
Fig. 3 shows the comparison between the proposed algorithm and two-point correction algorithm, and the comparison between the proposed algorithm and Kalman filter based non-uniformity correction algorithm. The results show that the proposed algorithm is effective.



(a) Raw image(20℃) (b) Corrected image(20℃)



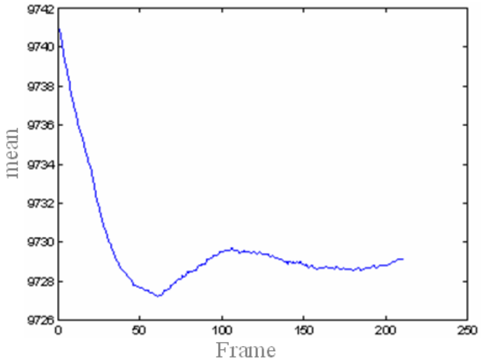
(c) Raw image(40℃) (d) Corrected image(40℃)



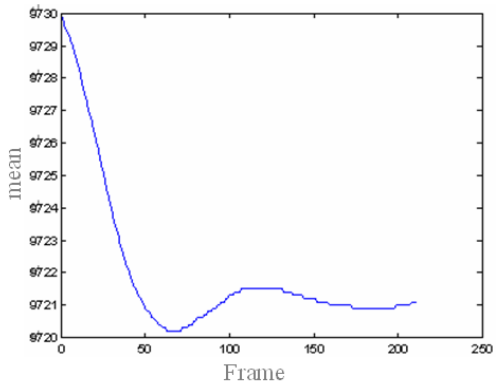
(e) Scenery image

(f) Corrected scenery image

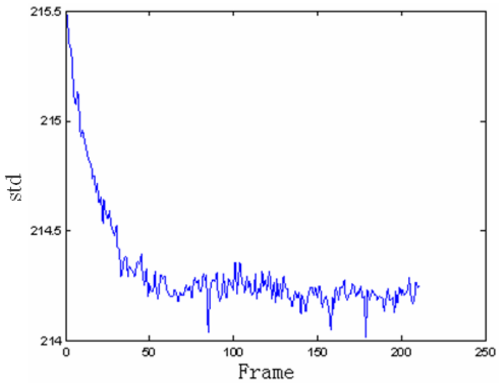
Fig. 1 Part of the experimental results



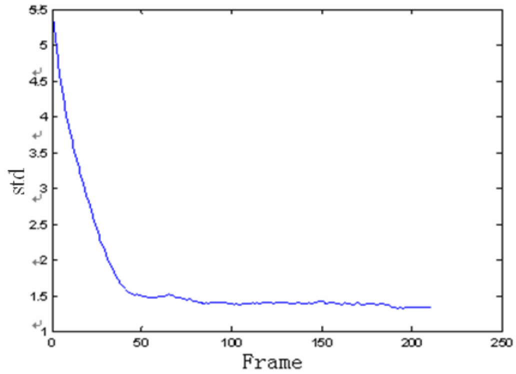
(a) Mean changes with frame before correction



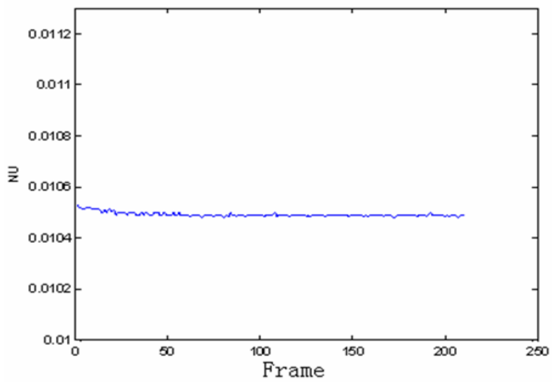
(b) Mean changes with frame after correction



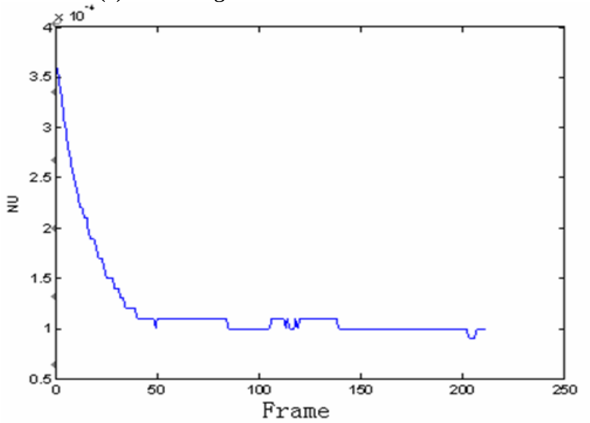
(c) Std changes with frame before correction



(d) Std changes with frame after correction

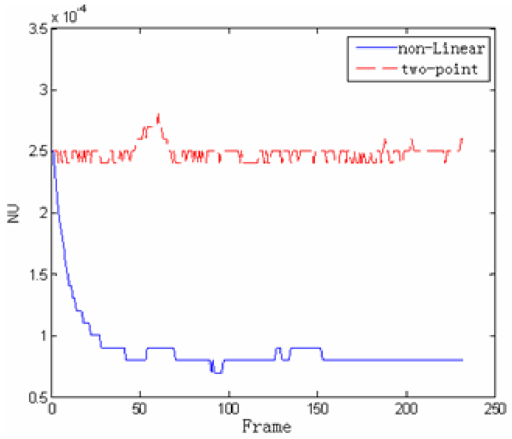


(e) NU changes with frame before correction

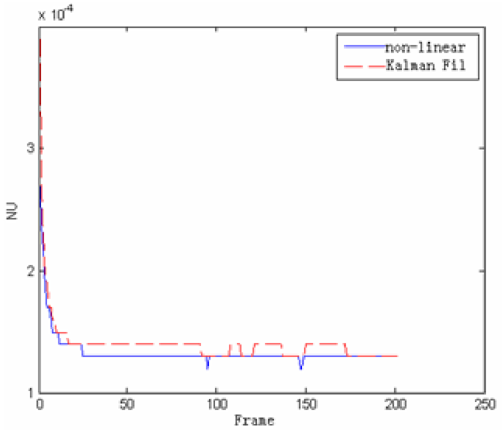


(f) NU changes with frame after correction

Fig. 2 An example of non-uniformity correction test



(a) Compared with two-point correction



(b) Compared with Kalman filter based correction

Fig. 3 Results compared with other approaches

IV. Conclusion

In this paper, a novel non-uniformity correction algorithm based on non-linear fit is proposed. The algorithm combines the advantages of multiple-point correction and scene-based algorithm. The use of three-order four-parameter polynomial can better fit the practical response of the IRFPA. In order to keep the non-uniformity correction effect, Kalman filter based algorithm with modified factor is introduced to process time drift. Primary experimental tests show that the proposed algorithm is successful. However, there is a long way to go for getting into practical use. In the next step, the discussion will be focused on the real-time processing, correction effectiveness and stability.

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