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Non-uniformity Correction Algorithm Based on Polynomial Fit Estimation

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Authors' contributions

This work was carried out in collaboration between all authors. Author YW designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Authors ZY and ZZ managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Because of many advantages such as all-weather work, passive imaging, high sensitivity, high frame frequency and simple structure, etc., IRFPA (infrared focal plane array) sensors have become popular in civil and military applications. However, images obtained by IRFPA suffer from a common problem called FPN (fixed pattern noise), which severely degrades image quality and limits the infrared imaging applications, and they can hardly be used without non-uniformity correction (NUC) on IR image. Therefore, it is urged to perform the NUC processing. As we all know, the algorithms of non-uniformity correction can be classified into two main categories, the calibration-based algorithm and the scene-based algorithm. But each kind of algorithm has its disadvantages, in order to make up for the limitations, a novel non-uniformity correction algorithm based on polynomial fit estimation and a modified factor is proposed, which combines the advantages of the two algorithms. Experimental results demonstrate that the proposed NUC algorithm has a good NUC effect with a lower non-uniformity ratio.

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Keywords: Non-uniformity correction; polynomial fit estimation; two-point correction; temporal Kalman filter.

1. INTRODUCTION

Infrared focal plane array (IRFPA) sensors are widely used in a range of military and civil 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 array (IRFPA) imaging system has many advantages, such as all-weather work, passive imaging, good reliability, high sensitivity, high system operating frame frequency, and etc. 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 can be classified into two main categories: calibration-based algorithm and scene-based algorithm. 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, usually it is unable to adapt the time varying scenery or the scenery with the temperature out of the calibrated temperature scope; while the 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 [2,3] correction technology is now one of the main research focuses in infrared image processing. Many algorithms have been proposed, such as constant-statistical algorithm [4], temporal high-pass filter technique [5], neural-network algorithm [6,7], Kalman filter algorithm [2,8,9], 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 effects of time drift, a novel non-uniformity correction algorithm based on polynomial fit estimation and a modified factor 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 even though the time drift exists.

The rest of the paper is organized as follows. In Section 2 the algorithm is described and its flow diagram is given. The experiment results are presented in Section 3, followed by the discussion and conclusion.

2. ALGORITHM DESCRIPTION

The flow chart of the proposed algorithm is shown in Fig. 1. From the figure, we can see there are two parts to calibrate the images. The first part in the dotted line box is off-line one, where four correction parameters for each pixel are estimated. Then by means of the estimated parameters, the infrared image can be corrected roughly. In order to obtain better corrected image, Kalman filter is introduced. Moreover, a modified factor is adopted to adjust the filtered output image so that the corrected image can be adapted to the shift scenery.

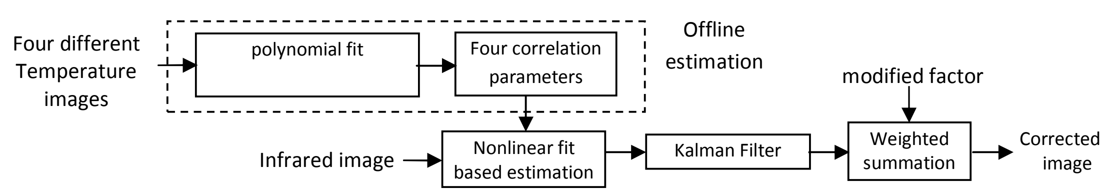


Fig. 1. The flow diagram of non-linear fit based non-uniformity correction algorithm

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 via estimating the parameters of two points calibration. 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

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

Where $T_{ij}(n)$ is the average quantity of photons collected by the ijth detector at the nth frame, A_{ij}, B_{ij}, C_{ij} and D_{ij} are respectively the four parameters associated with the ijth detector.

From formula (1) we know if we want to obtain the above four parameters, four equations are required. Therefore, at least four images associated with different temperatures are needed. Once the parameters are estimated, the input non-uniform image can then be corrected.

Considering time drifting, we adopt the temporal Kalman filter to process the correction parameters of two points calibration accompanied with a modified factor $M_k(i,j)$ (can be seen in formula (4)). The detailed process of the algorithm can be described as follows.

Step 1: Open four uniformly distributed blackbody images with different temperatures;

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,

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

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

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

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

Where $f_{ij}(n)$ is the gray value of pixel (i,j) in nth input image, n is the frame number, and it starts from 1.

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

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

$$Y_k(i,j) = H_k(i,j)X_k(i,j) + V_k(i,j) \tag{5}$$

Where $X_k(i,j) = [\alpha_k(i,j), \beta_k(i,j)]^T$,

$$\Phi_k(i,j) = \begin{bmatrix} a_k & 0 \\ 0 & b_k \end{bmatrix},$$

$$H_k(i,j) = [CG_{ij}(n), 1],$$

$$M_k(i,j) = \begin{bmatrix} 1-a_k & 0 \\ 0 & 1-b_k \end{bmatrix}\hat{X}_0,$$

$$\hat{X}_0 = [CG_{ij}(1) \quad 0]^T, \quad n \geq 1$$

$W_k(i,j)$ and $V_k(i,j)$ are white noise respectively, their variance are,

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

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 R_k can be assigned to 0.05.

Via the estimated status $\hat{X}_k(i, j) = \left[\hat{\alpha}_k(i, j) \quad \hat{\beta}_k(i, j)\right]^T$ by temporal Kalman filter, the modified non-uniformity correction gray $CG'_{ij}(n)$ can be estimated,

$$CG'_{ij}(n) = a_k \hat{\alpha}_k(i, j) CG_{ij}(n) + b_k \hat{\beta}_k(i, j). \quad (6)$$

In terms of formula (6), the corrected image with the gray $CG'_{ij}(n)$ owns a lower level NU and gray standard deviation and then can be processed by corresponding algorithms.

3. 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. 2 is some experimental results for several homogeneous distribution blackbody images with different temperature and without time drift (such as 20℃, 25℃, 30℃, 35℃, 40℃, 45℃, 50℃) by using the proposed algorithm. As can be seen in the figures, the algorithm has achieved good effects. Fig. 3 gives the results for the blackbody images with time shift and the scenery images. From the results, we can see the proposed algorithm is effective no matter whether the images have time drift or not. Fig. 4 is two examples of non-uniformity correction test, one (Fig. 4(a)-4(f)) is for the constant blackbody images without time drift, another (Fig. 4(g)-4(l)) is for the blackbody image with time drift. It shows the changes of mean, standard deviation and non-uniformity before and after non-uniformity correction. From the figure we can see the standard deviation and the non-uniformity after corrected keeps lower and steady level unlike corrected before. Here non-uniformity(NU) is defined as

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

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, $\bar{f}$ is the mean of whole image,

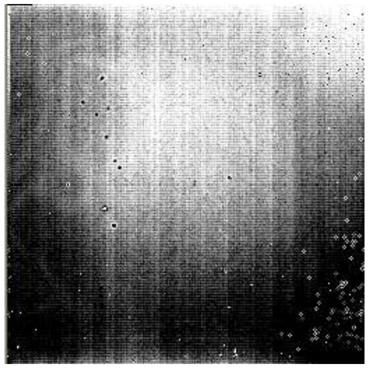
$$\bar{f} = \frac{1}{N} \sum_{i,j} f_{ij} .$$

As is seen in Fig. 4, 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.

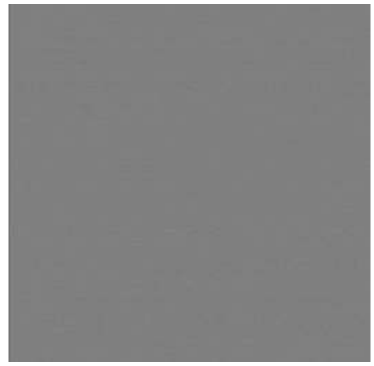
Table 1 gives the comparison results for five different image sequences between the proposed algorithm and two-point correction algorithm. The NU values in the table are the means for the sequences, respectively. From the results we can see the results of our proposed algorithm are excellent, which is superior to the two-point NUC algorithm and reaches the expectation. Fig. 5 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.

Table 1. The comparison of proposed algorithm with two-point NUC algorithm

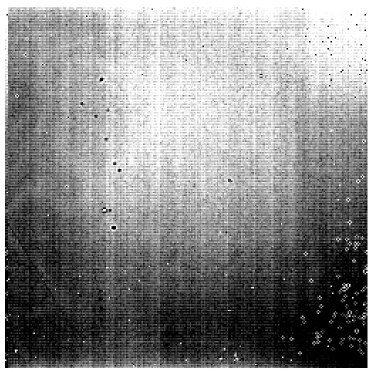
Image sequence	Expected results	Results of proposed algorithm	Results of two-point NUC algorithm
1	NU<3‰	0.11‰	0.33‰
2	NU<3‰	0.12‰	0.43‰
3	NU<3‰	0.32‰	0.44‰
4	NU<3‰	0.32‰	0.38‰
5	NU<3‰	0.09‰	0.25‰



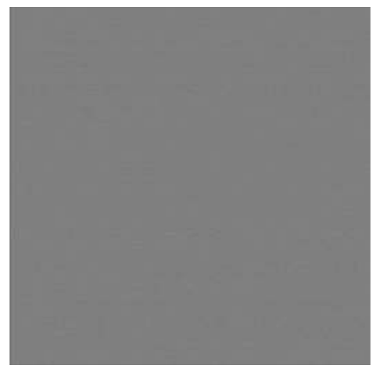
(a) Raw image(20℃)



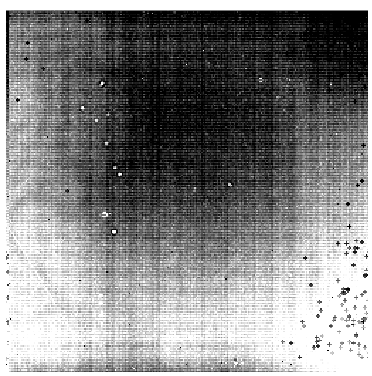
(b) Corrected image(20℃)



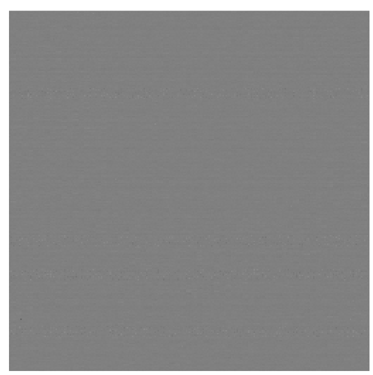
(c) Raw image(25℃)



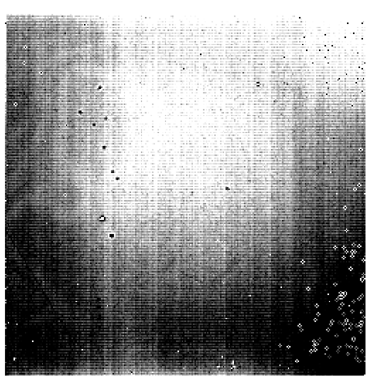
(d) Corrected image(25℃)



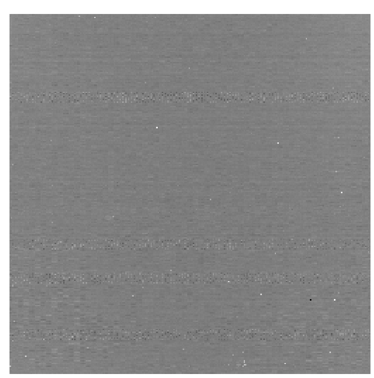
(e) Raw image(30℃)



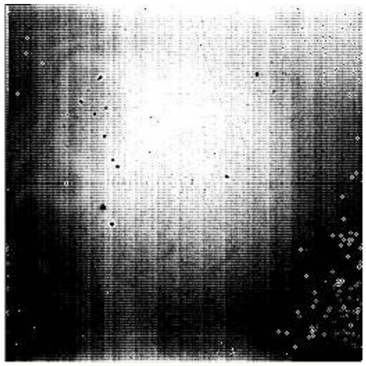
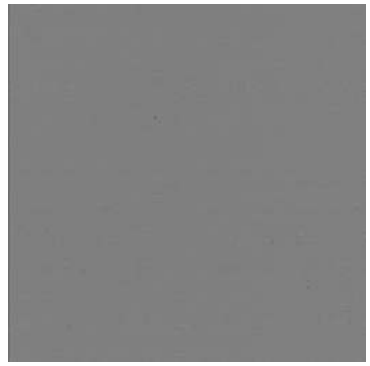
(f) Corrected image(30℃)



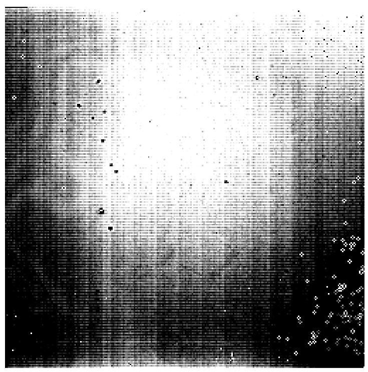
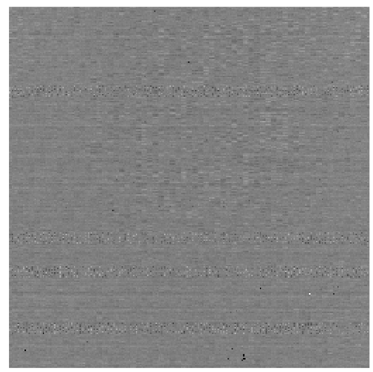
(g) Raw image(35℃)



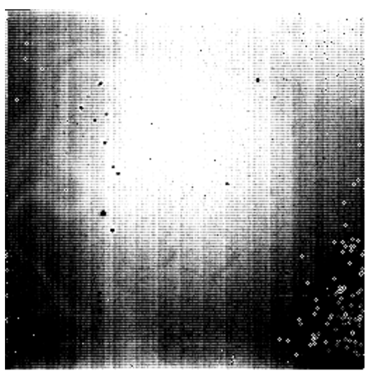
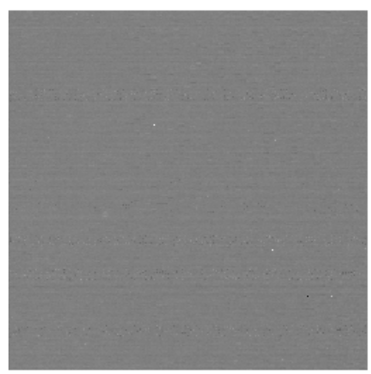
(h) Corrected image(35℃)

(i) Raw image(40℃) (j) Corrected image(40℃)

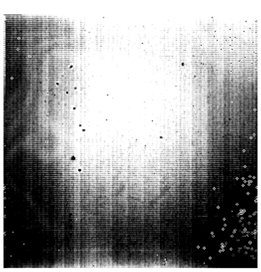
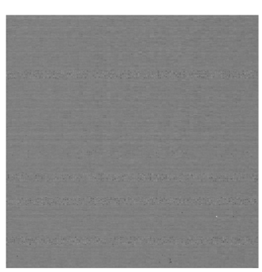
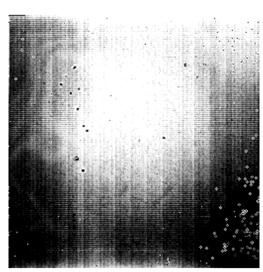
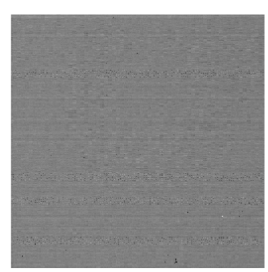



(k) Raw image(45℃) (l) Corrected image(45℃)

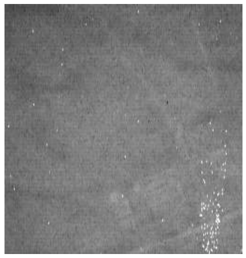



(m) Raw image(50℃) (n) Corrected image(50℃)

Fig. 2. Part of the experimental results for blackbody images without time shift

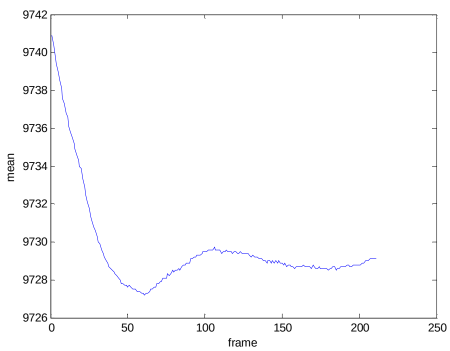
(a) 51^{st} frame raw image (b) Corrected image (c) 100^{th} frame raw image (d)corrected image



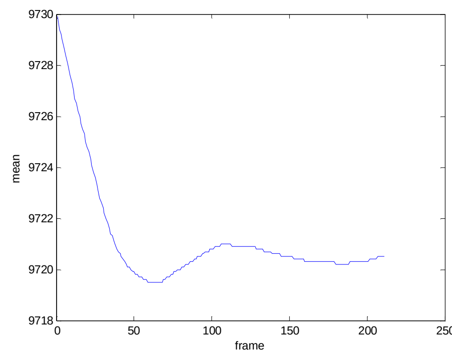
(e) Scenery image

(f) Corrected scenery image

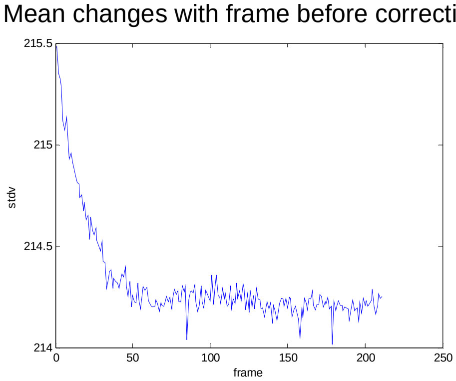
Fig. 3. Part of the experimental results for blackbody images with time drift and scenery images



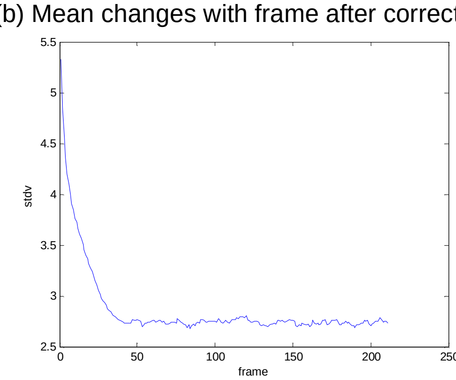
(a) Mean changes with frame before correction



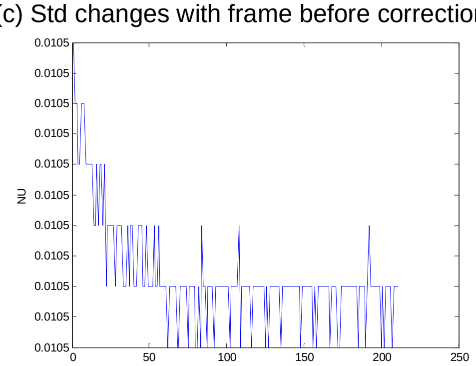
(b) Mean changes with frame after correction



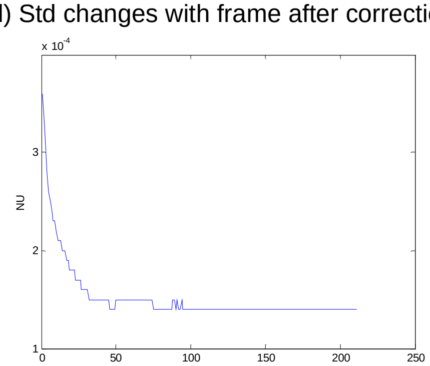
(c) Std changes with frame before correction



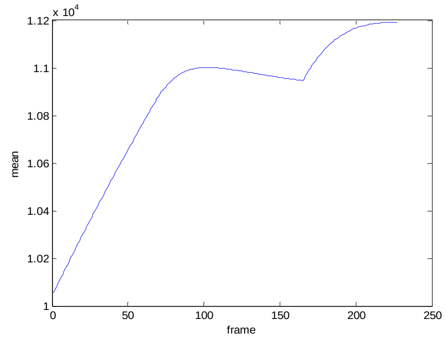
(d) Std changes with frame after correction



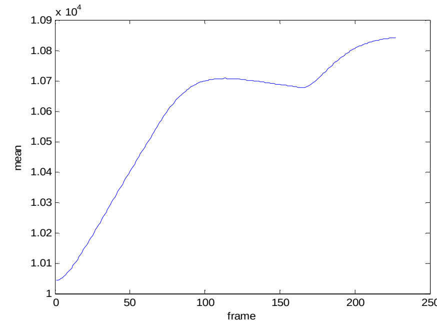
(e) NU changes with frame before correction



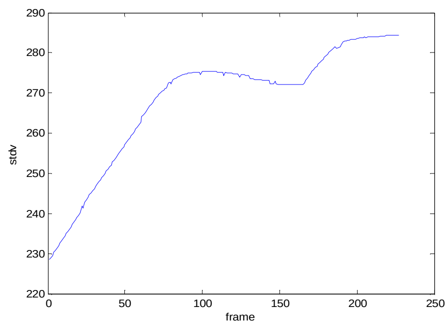
(f) NU changes with frame after correction



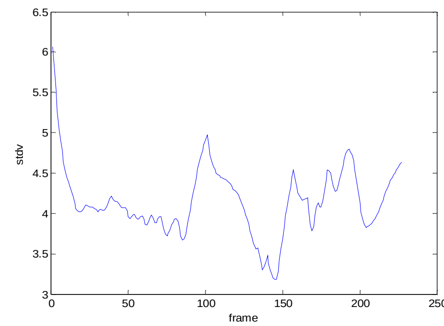
(g) Mean changes with frame before correction



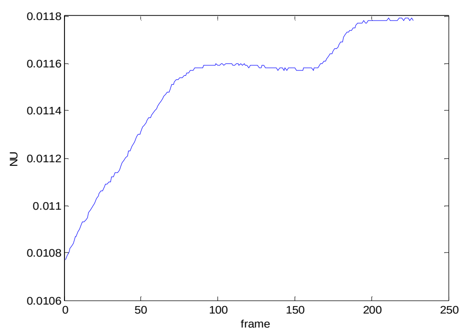
(h) Mean changes with frame after correction



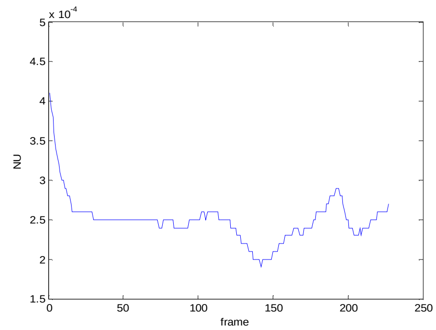
(i) Std changes with frame before correction



(j) Std changes with frame after correction

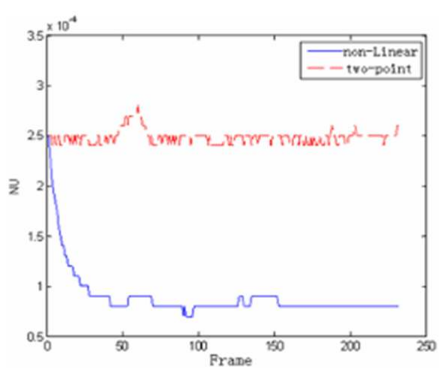


(k) NU changes with frame before correction

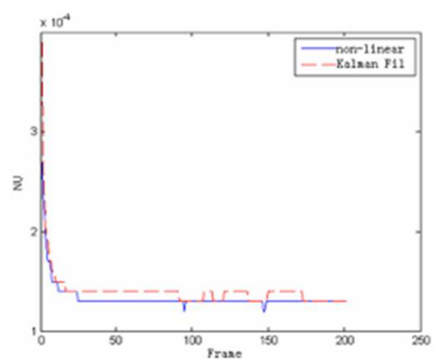


(l) NU changes with frame after correction

Fig. 4. Two examples of non-uniformity correction test



(a) Compared with two-point correction



(b) Compared with Kalman filter based correction

Fig. 5. Results compared with other approaches

4. CONCLUSION

In this paper, a novel non-uniformity correction algorithm based on polynomial 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 a_k and b_k is introduced to process time drift. Primary experimental tests show that the proposed algorithm (non-linear/polynomial algorithm) is successful. However, there is a long way to go for getting into practical use. In the next step, the research will be focused on the real-time processing, correction effectiveness and stability.

DECLARATION

Some part of this manuscript was previously presented and published in the conference “World Academy of Science, Engineering and Technology”, December 2012 Perth, the available link is“ http://waset.org/publications/8169/a-novel-non-uniformity-correction-algorithm-based-on-non-linear-fit”, Vol 6, 2012-12-23 [10].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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