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改进的基于积分时间定标的红外焦平面阵列非均匀性校正算法

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摘　要:红外焦平面阵列各探测元响应的非均匀性降低了图像的质量和温度分辨率,定标类和场景类校正算法为解决该问题提供了可行的途径.传统的基于黑体定标的校正算法由于其简单有效而被广泛使用,但是其缺点在于依赖黑体及其相关控温装置.本文提出了一种改进的基于积分时间定标的两级校正算法.在保持入射辐射不变的情况下,首先通过改变积分时间得到系列响应数据,然后利用最小二乘法估计出两点校正所需的初始校正系数,并对不同积分时间下的响应数据进行初校正,最后估计出一点校正系数.实验结果证明该方法具有计算量小、校正准确度高的优点,可取得优良的校正效果,并易于在硬件平台中实现.

关键词:非均匀性校正;积分时间;红外焦平面阵列;最小二乘

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Improved Non-uniformity Correction Algorithm Based on Integration Time Calibration for IRFPA

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Abstract: The infrared image quality and temperature resolution is degraded significantly by the non-uniformity response of infrared focal pattern array. Calibration-based and scene-based non-uniformity correction algorithms provide feasible way to handle this problem. Due to its simplicity and accuracy, traditional blackbody calibration-based non-uniformity correction method is widely used but with the disadvantage of highly dependence on the existence of blackbody and its temperature control equipment to provide uniform irradiances. In this paper, an improved two-level non-uniformity correction algorithm based on integration time calibration was proposed. Given the irradiance, the different response data is first obtained through integration time variation. Then the least square method is used to estimate the initial gain coefficients and bias coefficients for two point correction algorithm. Finally, the one point correction coefficients are estimated throuth two point correction of different response data. Experimental results show that the proposed algorithm has the merits of low complexity, high precision, excellent non-uniformity correction performance, and can easily be integrated into hardware platform.

Key words: Non-uniformity correction; Integration time; Infrared focal plane arrays; Least square

OCIS Codes: 100.2550; 110. 3080

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0 Introduction

Infrared focal plane array (IRFPA) is widely used in military and civilian applications. Due to the material defects and manufacturing limitation, the non-uniformity response of detectors is inevitable, and also produces fixed pattern noise (FPN). FPN corrupt infrared images severely and must be corrected first in practical applications. Non-uniformity correction (NUC) algorithm is the key technology to remove the FPN[1].

Currently, the NUC algorithms can be divided into two categories[2], one is based on calibration, and the other is based on scenes. The traditional calibration method is based on blackbody, response data is gathered when blackbody′s temperature is changed. Therefore, a linear or S-curve response model could be obtained. Calibration based methods mainly consist one point correction (OPC) algorithm[3], two point correction (TPC) algorithm and multi-point correction (MPC) algorithm[4-6]. TPC algorithm achieves more precision result than the OPC algorithm when used in typical linear model. MPC algorithm also achieves better result than the TPC algorithm when used in S-curve model.

Scene-based non-uniformity correction (SBNUC) algorithm uses series of scene response data to update the correction coefficients. Because the detector response always has the problem of random drifting with time, temperature and other external conditions, scene-based algorithm has the advantage of self-adaptive and more accurate. Currently, the scene-based correction algorithm mainly consist statistical methods[7] and registration-based methods[8-10]. Statistical methods, such as temporal high-pass filtering, constant statistics method, constant range method, Kalman filtering method, generally require the relative motion between target scene and IRFPA camera. Registration-based correction algorithm, such as O′Neil′s method, motion compensated method, algebraic scene-based method *etc*. In this kind of algorithms, computation is complex and storage demands are relatively high. The correction errors are transmitted accumulatively step by step, which makes these methods difficult to achieve a practical effect.

Although the scene based non-uniformity correction algorithm is more effective to the variation of external conditions, calibration based NUC algorithm is still widely used due to its simplicity, accuracy and easily implementation. For most commercial IR cameras, the NUC procedure is performed during the factory calibration process and the NUC coefficients are stored in the firmware. In some special occasions, calibration based NUC is also the first choice considering the complexity of scene based NUC method. But the traditional calibration based NUC method seriously dependent on the blackbody and its temperature control equipment; this brings much inconvenient and additional cost. In this paper, a new NUC algorithm based on integration time calibration is proposed. In the calibration process, the blackbody is abandoned, different response data is gathered by changing integration time. Through improved TPC algorithm, gain and bias coefficients are calculated, and NUC algorithm could be implemented easily. The experimental results validate that the proposed method achieves better NUC performance.

1 Traditional TPC algorithm

In engineer, the most used NUC method is TPC algorithm. Traditional TPC calibration is performed by exposing the detector to a uniform background at two different radiation intensities, blackbody is usually used. If the system parameters are changed or if a period of time had elapsed since the last calibration, the correction quality usually degrades.

1.1 Traditional TPC algorithm

The traditional blackbody calibration-based TPC (BTPC) algorithm is based on the assumption that the response characteristic of the infrared detector is linear. Two uniformity irradiances are chosen as the correction points, and the detector response data under the two points are recorded respectively. Then the average value of all detectors is calculated respectively. The correction coefficients are obtained from the following formulas

$$G(i,j)=\frac{\overline{X}_{\mathrm{H}}(i,j)-\overline{X}_{\mathrm{L}}(i,j)}{X_{\mathrm{H}}(i,j)-X_{\mathrm{L}}(i,j)} \tag{1}$$

$$B(i,j)=\frac{X_{\mathrm{H}}(i,j)\overline{X}_{\mathrm{L}}(i,j)-X_{\mathrm{L}}(i,j)\overline{X}_{\mathrm{H}}(i,j)}{X_{\mathrm{H}}(i,j)-X_{\mathrm{L}}(i,j)} \tag{2}$$

where $G(i,j)$ and $B(i,j)$ are gain and bias coefficients of pixel (i,j) respectively. $X_{\mathrm{H}}(i,j)$ and $X_{\mathrm{L}}(i,j)$ are response values of each pixel at high and low blackbody temperature, $\overline{X}_{\mathrm{H}}(i,j)$ and $\overline{X}_{\mathrm{L}}(i,j)$ are average value of $X_{\mathrm{H}}(i,j)$ and $X_{\mathrm{L}}(i,j)$. The output image after TPC is

$$X'(i,j)=G(i,j)X(i,j)+B(i,j) \tag{3}$$

$X(i,j)$ is the original uncorrected image, $X'(i,j)$ is the output image after TPC operation.

For calibration data, the performance of NUC algorithm is evaluated by a parameter called as residual non-uniformity (RNU). The RNU is defined as standard deviation (SD) of the corrected FPA signal divided by mean signal. It is defined by

$$\mathrm{RNU}=\frac{\sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(X(i,j)-\overline{X}(i,j)\right)^{2}}}{\overline{X}(i,j)} \tag{4}$$

where $X(i,j)$ is the pixel grayscale value, and $\overline{X}(i,j)$ is the averaged grayscale value of all pixels. For scene data, the above formula is not suitable to evaluate the performance of NUC algorithm. Instead, the roughness index ρ is often used as a measure of the RNU present in a corrected image. The roughness index is calculated as follows

$$\rho=\frac{\| h_1 * I \|_1 + \| h_2 * I \|_1}{\| I \|_1} \tag{5}$$

where h_1 and h_2 are a horizontal and a vertical difference filter respectively, I is the corrected image under analysis, $\| I \|_1$ is the L_1 norm of I, and $*$ represents discrete convolution.

1.2 The shortcomings of BTPC

The traditional BTPC algorithm has a simple structure, and can be realized easily in real time hardware platform, so it is still be widely used in different thermal imaging system. But it has shortcomings. Firstly, its calibration process relies on blackbody and temperature control equipment, this results additional time and finance cost. Secondly, the gain and bias coefficients obtained in one integration time can't take effect when integration time is changed. The following gives an example about the defect of the BTPC algorithm.

We use UL04171 to gather a series of IR images. UL04171 is an infrared device sensitive to radiation in the long wave spectral range. It includes a micro-bolometer Focal Plane Array (FPA) comprised of a 640×480 elements, and a thermoelectric stabilizer (TEC) integrated into a miniaturized metal packaging. Its current is integrated in a current-voltage conversion stage located at the end of each column. The current-voltage conversion is performed by a Capacitance Trans-Impedance Amplifier (CTIA).

Two frames of response data are gathered when integration time is fixed in 35 μs, blackbody' s temperature is set in 293K and 313K separately. When gain and bias coefficients are calculated from Eq. (1) and (2), use these coefficients to correct the scenes captured in four different integration times. Fig. 1 shows the result of the experiment. In order to give an intuitive contrast, the images are corrected with BTPC method and blind pixel compensation (BPC) method.

The roughness indexes of four original uncorrected images are approximately 0.81, only the image obtained in 35 μs is well corrected, the other images still have much residual non-uniformity. From the Fig. 1 we can see, the correction coefficients obtained in one integration time can't take effect to the images that whose integration time is changed. The more drastic integration time changes , the poorer image quality after BTPC.

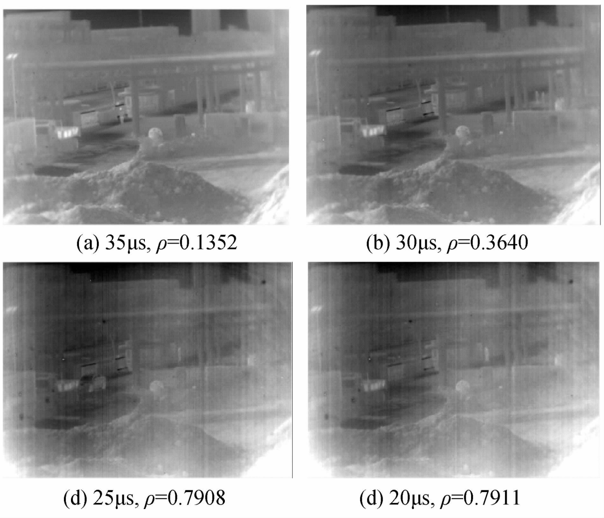

(a) 35μs, ρ=0.1352
(b) 30μs, ρ=0.3640
(d) 25μs, ρ=0.7908
(d) 20μs, ρ=0.7911

Fig. 1 BTPC result

Integration time is a very important parameter for IR cameras. In practical use, the optimal integration time always vary with the incidence radiation. When the target is too small or far away, big integration time is often used; when the target is near or too big, small integration time should be used. In engineering, IR cameras often have several integration times, each integration time corresponding to a group of gain and bias coefficients. If an $M\times N$ IRFPA has n integration times, $2n\times M\times N$ correction coefficients should be stored in hardware when BTPC algorithm is used.

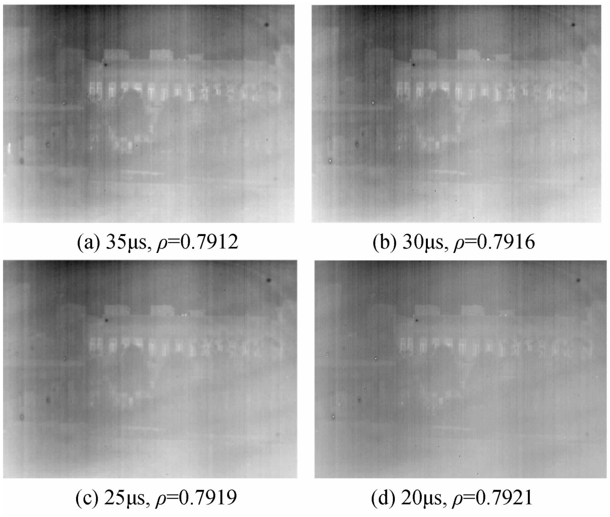
2 New ITPC Algorithm

Using different response data to calculate the gain and bias coefficients is the key essence of the traditional BTPC algorithm. The different response data could be obtained by changing blackbody' s temperature, and could also be obtained by integration time variation. This paper presents the study of integration time-based TPC algorithm (ITPC).

2.1 Traditional formulas used in ITPC

We still assume the IRFPA' s response module is linear. Eq. (1) and (2) are used to calculate the correction coefficients. The images used in calibration are separately obtained in 20 μs and 35 μs while the blackbody' s temperature is fixed in 298 K. Fig. 2 shows the result of the experiment.

The roughness indexes of four original uncorrected images are approximately 0.81, while the roughness indexes of corrected images are approximately 0.79. This shows the fact that the correction coefficients obtained from the traditional TPC formulas can hardly remove the FPN when integration time calibration is used, the residual NU still degrades the image quality.



(a) 35μs, ρ=0.7912
(b) 30μs, ρ=0.7916
(c) 25μs, ρ=0.7919
(d) 20μs, ρ=0.7921

Fig. 2 ITPC results

2.2 New ITPC algorithm

In this section, we proposed a new calculation method for TPC coefficients when integration time calibration is used. Assume $t_1, t_2, \cdots t_n$ are integration times of IRFPA, $t_1 < t_2 < \cdots < t_n$. When input uniform radiance is fixed, get original data $X_1, X_2, \cdots X_n$, X_k is the uncorrected data when integration time is t_k, $k=1, 2, \cdots n$. The NUC algorithm consist several steps as follows.

Step 1: Linear model for the IRFPA detectors is used based on the least square fitting method. The fitting model is expressed as Eq. (6).

$$X(i)=k(i)T(i)+b(i) \tag{6}$$

Where $k(i)$ and $b(i)$ are fitting coefficients, and they can be calculated through the following equation set

$$k(i)=\frac{N(\sum T(i)X(i))-(\sum T(i))(\sum X(i))}{\Delta} \tag{7}$$

$$b(i)=\frac{(\sum T^2(i))(\sum X(i))-(\sum T(i))(\sum T(i)X(i))}{\Delta} \tag{8}$$

$$\Delta=N(\sum T^2(i))-(\sum T(i))^2 \tag{9}$$

Calculate each pixel's fitting variance$\sigma(i)$

$$\sigma(i)=(\sum_{n=1}^{N} X_n(i)-k(i)t_n-b(i))^{1/2} \tag{10}$$

Step 2: Bad Pixel detection. If $\sigma(i) < a\bar{\sigma}(i)$ or $\sigma(i) > b\bar{\sigma}(i)$, then pixel i is bad pixel. a and b are experience values, usually $a \in [0.8, 0.9]$, $b \in [1.1, 1.2]$.

Step 3: $\bar{k}(i)$ is the average value of $k(i)$, $\bar{b}(i)$ is the average value of $b(i)$, set $klow=0.8\times\bar{k}(i)$, khigh $=1.2\times\bar{k}(i)$. Modify$k(i)$, calculate gain coefficients and bias coefficients.

$$k(i)=\begin{cases} k(i)=klow & \text{if } k(i)<klow \\ k(i) & klow\leqslant k(i)\leqslant khigh \\ k(i)=khigh & k(i)>khigh \end{cases} \tag{11}$$

$$Gain(i)=\bar{k}(i)/k(i) \tag{12}$$

$$Bias(i)=\bar{b}(i)-Gain(i)\times B(i) \tag{13}$$

Step 4: Use $Gain(i)$ and $Bias(i)$ to correct the original infrared imagesX_1, X_2, $\cdots X_n$, the corrected image is $Y_1, Y_2, \cdots Y_n$. The correction formula is

$$Y_n(i)=Gain(i)\times X_n(i)+Bias(i) \tag{14}$$

Step 5: Calculate the average value of $Y_n(i)$, named $\overline{Y_n}$.

$$OB_n(i)=Y_n(i)-\overline{Y_n} \tag{15}$$

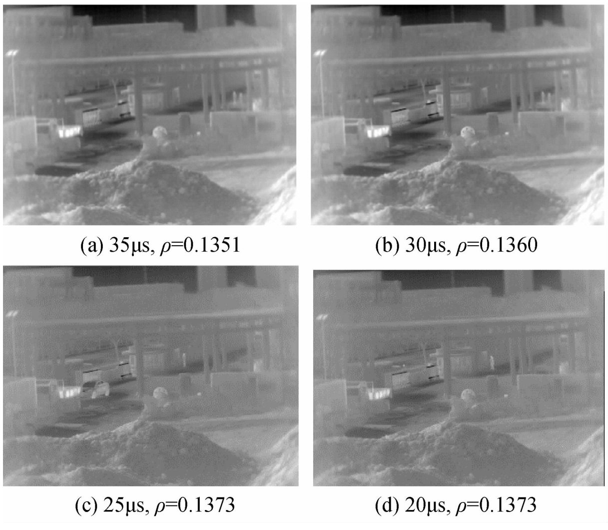
$$OBAVE(i)=\sum_{n=1}^{N} OB_n(i)/N \tag{16}$$

Step 6: To an uncorrected scene image$S(i)$, perform the final NUC formula

$$SC(i)=S(i)\times Gain(i)+Bias(i)-OBAVE(i) \tag{17}$$

3 Experiment result

We use a LW uncooled micro-bolometer to test this ITPC algorithm. The IR Camera is covered with lens cap at room temperature; images are obtained when integration time is respectively set to 20 μs, 25 μs, 30 μs and 35 μs, and Fig. 3 gives the ITPC result. The roughness indexes of four original uncorrected images are approximately 0.81. After correction, the roughness indexes are approximately 0.13.



(a) 35μs, ρ=0.1351
(b) 30μs, ρ=0.1360
(c) 25μs, ρ=0.1373
(d) 20μs, ρ=0.1373

Fig. 3 ITPC results

From the image we can see, the correction coefficients obtained by proposed ITPC method also can achieve good NUC effect compared to the traditional BTPC method. More importantly, when integration time changes, the NUC effect is affected slightly, the residual non-uniformity changes little. To the same integration time image, the NUC effect of BTPC and ITPC is almost the same, to the other integration time image, ITPC is much better than BTPC.

4 Conclusions

A novel non-uniformity correction algorithm, integration time-based calibration correction, is proposed for an IRFPA. The performance of the algorithm is discussed compared to the traditional blackbody-based TPC algorithm. The experiments with the real infrared images prove that the proposed ITPC algorithm can achieve better non-uniformity correction performance than the classic BTPC algorithm.

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