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A novel nonuniformity correction algorithm based on speeded up robust features extraction

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HIGHLIGHTS

- SURF method is effective in evaluating rotation and affine transformation.
- The NUC method based on SURF can eliminate low frequency spatial NU noise.
- The NUC method based on SURF can eliminate heavy NUC noise.

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ABSTRACT

The traditional image-registration based non-uniformity correction algorithm assumes that the displacements of inter-frame images are horizontal or vertical which ignores rotation, affine transformation, etc. This restriction results in low registration accuracy and then depresses the quality of nonuniformity correction. In this paper, we bring forward a novel nonuniformity correction algorithm based on speeded up robust features extraction (SURF). The feature points are extracted by hessian operator in the algorithm and are described in use of the 64-dimensional descriptor. Then the algorithm gets all the matching pairs by matching threshold, and all matching pairs can be used to estimate transform converting relations between the two consecutive images. The converting relations combined with the steepest gradient descent method can adaptively correct the gain and offset calibration parameters, which can get the accurate registration including rotation and affine transformation, and then reduce excessive noise and ghost artifacts in the process of correction. The experiments also show that our algorithm can solve the registration accuracy problem in complex conditions, and improve the correction results effectively.

1. Introduction

The Infrared imaging technique is one that transforms the infrared radiation to visible light, which in fact is a wavelength conversion technique. All objects whose temperature is higher than 0 K constantly radiate infrared radiation, and the energy is proportional to the object temperature, therefore we can utilize the differences of radiation distribution of scenes to achieve the target image. In use of this technique, we can clearly observe complex battle fields at weak illumination conditions. This technique has the advantages that cannot be easily interfered and can recognize camouflaged targets.

In spite of so many advantages of infrared imaging technology, it also has some restricts which limit its wide use, such as nonuniformity because of the semiconductor material property, technological level and outer circumstance temperature, the resulting nonuniformity of infrared image has become the bottleneck to restrict the development of infrared imaging technology. The nonuniformity of device leads to that the output image of infrared imaging system is polluted by fixed pattern noise and surrounding low-frequency noise, which decline the imaging quality seriously. Therefore, to effectively reduce the FPAs' nonuniformity noise is an essential procedure during the imaging processing [1]. The nonuniformity correction (NUC) methods of IRFPA are divided into two categories: calibration-based NUC methods and scene-based NUC methods. Calibration-based NUC methods consist of one-point correction, two-point correction and multi-point correction. Quadratic curve-fitting model [2] has also been proposed and successfully implemented into the correction. The calibration-based methods have the benefits of high precision, easy implementation and so on, but drift problem of correction coefficients along with other issues also exists. It is brought by temperature drift and pixel aging. One solution is to periodically update the correction

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coefficients, but it increases the difficulty of system maintenance. Thus scene-based NUC technology because of its advantages of no-required pre-calibration and high adaptability becomes the main direction of future development.

Scene-based NUC algorithms consist of two broad categories, one is based on data statistics, including temporal high-pass method [3], neural network method [4] and corresponding expansions in this form, often accompanied with serious ghost artifacts. The other is based on image registration [5]. The method often assumes that in a short time interval the corresponding pixels of two consecutive images in same position of scene have same response; hence it is necessary to calculate the exact displacement of two consecutive images. The regular method utilizes phase correlation [6] to estimate the displacement, but neglecting rotation and scaling, which virtually affect the accuracy of correction coefficients. Therefore, in this paper we proposed an NUC algorithm that uses SURF operator to achieve the inter-frame image registration. The experiments prove that it can obviously improve the correction performance at the expense of some correction speed.

2. Nonuniformity correction theory of IRFPA

2.1. Response model of IRFPA

The nonuniformity of IRFPA is that for the same infrared radiation, different pixels of detectors have different responses, even for a signal pixel-detector, same infrared radiation increment will cause different response increment. Both theory and experiment have proved that the response curve is a 'S' type curve, it is firstly cut-off at low radiation, then slowly rising and linear growing to saturation. As Fig. 1 shows, for a long period in the middle curve, it can be regarded as an approximate linear growth area. Focusing on this area, the inputs of array pixels satisfy a linear relationship to the outputs.

Supposing the gain and offset coefficients of the pixel in row i and column j at frame n are $G_n(i,j)$ and $O_n(i,j)$ respectively, then the output signal $Y_n(i,j)$ is:

$$Y_n(i,j) = G_n(i,j) * X_n(i,j) + O_n(i,j) \tag{1}$$

where $X_n(i,j)$ is the input irradiance. By the inverse transformation of $Y_n(i,j)$ we can calculate the real irradiance $X_n(i,j)$ and complete the NUC process. It can be expressed as:

$$X_n(i,j) = W_n(i,j) * X_n(i,j) + B_n(i,j) \tag{2}$$

where $W_n(i,j) = \frac{1}{G_n(i,j)}$, $B_n(i,j) = -\frac{O_n(i,j)}{G_n(i,j)}$.

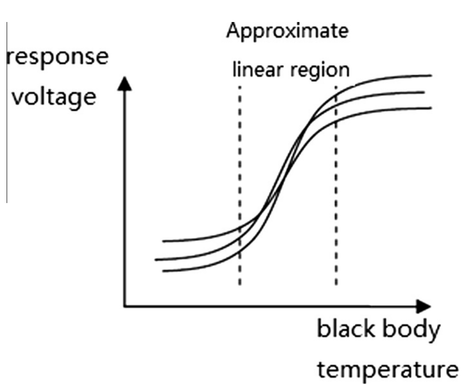

Fig. 1. Diagram of response curve of IRFPA.

2.2. Image registration based NUC

Image registration based NUC algorithms gain rapid development due to their good performance. The typical example is the image-registration based least-mean-square (IRLMS) NUC algorithm proposed by Zuo et al. [7], this algorithm assumes the gray between two consecutive images keep constant, that the incident radiation along the trajectory of pixels remain unchanged, and it assumes that there are only horizontal and vertical displacements between inter-frames. Under this assumption, the input irradiation satisfies the equation below:

$$X_n(i,j) = X_{n-1}(i - d_n(i), j - d_n(j)) \tag{3}$$

where $d_n(i)$, $d_n(j)$ are the vertical and horizontal displacements of frame n relative to frame $n-1$ separately.

The IRLMS algorithm constructs the error function between estimated values of the two adjacent frames:

$$e_n(i,j) = \widehat{X_n}(i,j) - \widehat{X_{n-1}}(i - d_n(i), j - d_n(j)) \tag{4}$$

The modulation of gain and offset coefficients utilizes the minimization of mean square of error function as the criterion by the steepest gradient method as Eqs. (5) and (6) show as:

$$W_{n+1}(i,j) = \begin{cases} W_n(i,j) + a * e_n(i,j) * Y_n(i,j) & \text{when } i,j \text{ are in the overlapped area} \\ W_n(i,j) & \text{other} \end{cases} \tag{5}$$

$$b_{n+1}(i,j) = \begin{cases} b_n(i,j) + a * e_n(i,j) & \text{when } i,j \text{ are in the overlapped area} \\ b_n(i,j) & \text{other} \end{cases} \tag{6}$$

where a is the learning rate, whose recommended value is 0.5 in [7].

IRLMS algorithm achieves a good NUC performance based on image registration, but in conditions that only displacement exists, the performance declines when scaling, rotation, etc. exist. Therefore, it is necessary to improve the image registration method, and implement image registration in complex conditions.

Suppose that the movements in two consecutive images include displacement, affine transformation and rotation etc. Without loss of generality, we set the row i, column j pixel in frame n and row p, column k pixel in frame $n-1$ are the corresponding pixels, then Eq. (3) is rewritten as:

$$X_n(i,j) = X_{n-1}(p,k) \tag{7}$$

where $X_n(i,j)$ and $X_{n-1}(p,k)$ denote the input irradiate of the corresponding pixels in frame n and $n-1$ respectively. Eq. (4) is rewritten as:

$$e_n(i,j) = \widehat{X_n}(i,j) - \widehat{X_{n-1}}(p,k) \tag{8}$$

From Eqs. (7) and (8) the exact results are from accurate image registration, and in this paper we utilize SURF algorithm to extract the feature points and implement the image registration.

3. SURF feature extraction and image registration

3.1. SURF algorithm

SIFT algorithm is the angular point extracting and description algorithm proposed by David Lowe in 1999, and is summarized and improved in 2004. It can be used to process the image registration issue in complex conditions that include displacement, rotation and affine transformation, and has a strong matching ability and a certain anti-noise capability. Based on this, Bay et al. proposed a speeded up robust features (SURF) algorithm, an improvement of SIFT algorithm. It calculates the integral images and Hessian matrices which greatly raise the speed of feature point detection. The basically procedures are as follows: