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A combined temporal and spatial deghosting technique in scene based nonuniformity correction

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HIGHLIGHTS

- A combined temporal and spatial deghosting technique is proposed.
- The NUC parameters can be updated only in smooth areas.
- It can deal with the infrared sequences in which the background stays unchanged.
- The method can reduce FPN robustly without generating ghosting artifacts.

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ABSTRACT

The least mean square error based nonuniformity correction algorithm is a kind of classical method to reduce the fixed pattern noise in infrared focal plane array. It is well-known for its low cost of computation and storage resources. However, it suffers from the drawback that ghosting artifacts can be easily generated in the edge areas when the inter-frame motion slows. In this paper, a combined temporal and spatial deghosting technique is proposed. Both spatial correlation detection and temporal motion detection are used to gate the update of correction parameters. The experimental results demonstrate that the deghosting performance of the proposed method is superior to other deghosting methods.

1. Introduction

The least mean square (LMS) based nonuniformity correction (NUC) algorithm [1,2] is a classical method to reduce the fixed pattern noise (FPN) in infrared focal plane array (IRFPA) [3,4]. It is well-known for its low cost of computation and storage resources. However, the ghosting is a non-ignorable drawback in the LMS based NUC algorithms. The ghosting is always occurring when the scene motion slows or stops. Once the scene remains stationary for a while, the textures and the edges gradually degenerate and become blurred. The static scene "burns" into the NUC parameters. This results in a ghosting artifact in the original place after the motion resumes. And the ghosting artifacts can be seen for hundreds of frames before they are eliminated.

Fig. 1 gives an example of when the ghosting artifacts appear and disappear. In the figure, the top row is the original images, and the bottom row is the corresponding corrected images by an LMS based NUC algorithm, e.g., Scribner's algorithm [1]. The first column is the first frame of the infrared sequence, and the scene remains stationary for a while. By using Scribner's algorithm to reduce the FPN, the textures and the edges become blurred, as shown in the second column. The ghosting artifacts appear when the motion begins, as shown in the third column. They can be seen for a long period of time before they disappear, as shown in the last column.

To avoid ghosting artifacts, many algorithms have been proposed [2,5,6]. Vera and Torres considered that the ghosting artifacts are mainly generated by the fixed learning rates during updating the NUC parameters. Small step size should be adopted in the edge areas. So they improved Scribner's algorithm by adaptive learning rate [5]. Rossi also pointed out that the ghosting artifacts are generated mainly in strong edge areas. Instead of classical low pass filters, he introduced the bilateral filter, which can preserve edges [6]. Hardie pointed out that other deghosting algorithms only slow the burn-into process and do not eliminate the burn-into for long motion pauses. The ghosting artifacts generally occur when motion across the whole image or a part of the image temporarily slows or stops. Thus Hardie gated the update of the NUC parameters in such situations [2]. Hardie proposed a well

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Fig. 1. Examples in the infrared sequence processed by Scribner's algorithm [1]. The top row is the original images and the bottom row is the corresponding corrected images. From the left to the right: the first frame of the infrared sequence; the frame after the scene remains stationary for a while; the frame after the scene motion resumes; the frame after the scene keeps motion for hundreds of frames.

known principle in the LMS based NUC algorithms: no motion, no update.

The drawback of Hardie's deghosting method is that the update of NUC parameters is gated only by temporal pixel-to-pixel change. The scene information has not been taken into account. When the background stays unchanged, walking men, cars or other moving objects will make the static background burn into the NUC parameters. Hardie's method cannot gate the update of the NUC parameters in this situation, where ghosting artifacts can also be generated. A more robust deghosting method should stop the update of the NUC parameters by the information from both spatial domain and temporal domain. In this paper, a combined temporal and spatial deghosting method is proposed. In each frame, the NUC parameters of one detector can be only updated when (i) the response of the detector has high correlation with its neighborhood, and (ii) large temporal deviation of the detector's response exists.

1.1. Background

Infrared focal plane array (IRFPA) sensors are widely used in the fields of aviation, industry, agriculture, medicine, and scientific research [3,4]. However, the different photo-response of each detector within the IRFPA, caused by the manufacturing technique, results in nonuniformity. Then the FPN is superposed to the original image. To reduce FPN, many NUC algorithms have been proposed. They can be mainly classified into two categories: (i) calibration based NUC algorihms [7,8] (ii) scene based nonuniformity correction algorithms (SBNUC) [9–11]. The calibration based methods determine the NUC parameters by inserting extended blackbodies into the optical path and recording the detector responses at one or more background temperatures. However, the FPN is always influenced by such external conditions as ambient temperature, variation in the transistor bias voltage [1,7,12]. This results in that the response of each detector drifts slowly with the time lapse. Thus the periodical calibration is needed. However, this requires halting the infrared sensors, which is unbearable in most applications.

In contrast, the scene based methods determine the NUC parameters by the observed scene. For example, the SBNUC algorithms based on registration [9–11,13] adaptively update the NUC parameters by inter-frame registration; the SBNUC algorithms based on Kalman filter [14,15] use the Kalman filter to obtain the best NUC parameters; the SBNUC based on midway histogram equalization correct each column of the image by mid-histogram-equalize its neighborhood columns [16]. However, the registration based SBNUC algorithms assume that the motion between adjacent frames is consisted only of translation, ignoring any scaling, rotation or other warping of the images [17–20]. And other algorithms do require large sum of computational and/or storage resources. This limits their uses in the embedded systems of the infrared camera. Besides these algorithms, one classical SBNUC algorithm is based on the LMS error [1,2,7,21,22]. It adaptively updates the NUC parameters according to the LMS error between the corrected images and their desired images. It is well-known for its low cost of computation and storage resources. And the main drawbacks of the LMS based algorithms are that they do require continuous scene motion and ghosting artifacts can be easily generated [2]. Our work mainly focuses on the deghosting technique in the LMS based NUC algorithms, so that a simple, versatile and robust algorithm can be directly applied into the real-time infrared camera.

2. Deghosting method

2.1. Observation model

Assuming the photo-response of each detector in the IRFPA is linear in the operating response range, the output of the IRFPA is given by:

$$x_n(i,j) = a_n(i,j) \times \Phi_n(i,j) + b_n(i,j) + \epsilon_n(i,j), \quad (1)$$

where i,j are the spatial coordinates and the subscript n is the serial number of frames, $\Phi_n(i,j)$ stands for the real infrared radiation collected by of the (i,j)th detector, $a_n(i,j)$ and $b_n(i,j)$ are the gain and offset of the radiation-voltage response of the (i,j)th detector respectively, $x_n(i,j)$ is the observed image, and $\epsilon_n(i,j)$ is the random electrical noise.

The observed image is typically corrupted by FPN. To eliminate the FPN and provide an estimate of the true scene radiation $\Phi_n(i,j)$, NUC is required which is performed by applying a linear mapping to the output of the IRPFA. The NUC function is given by:

$$y_n(i,j) = g_n(i,j) \times x_n(i,j) + o_n(i,j), \quad (2)$$

where $g_n(i,j)$ and $o_n(i,j)$ are the gain and offset NUC parameters respectively, $y_n(i,j)$ is the corrected image. The SBNUC updates the gain and the offset NUC parameters according to the scene in real time.