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Registration method for infrared images under conditions of fixed-pattern noise

Chao Zuo *, Qian Chen, Guohua Gu, Xiubao Sui

National Defense Key Laboratory of Optoelectronic Engineering, Nanjing University of Science and Technology, Nanjing 210094, China

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ABSTRACT

This paper proposes a new registration method for infrared images under conditions of fixed-pattern noise (FPN). Conventional registration techniques are susceptible to FPN and it is therefore very desirable to have a registration algorithm that is tolerant to FPN. For this purpose, we utilize the difference of the cross-power spectrum of two discrete shifted images to suppress the noise power spectrum while the shifts information is well preserved. In particular, we show that the phase of the cross-power spectrum difference is a periodic two-dimensional binary stripe signal with the exact shifts determined to subpixel accuracy by the number of periods of the phase difference along each frequency axis. Robust estimates of shifts can be obtained by transforming its discontinuities to Hough domain. Experimental results show that the proposed method exhibits robust and accurate registration performance even for the noisy images that could not be handled by conventional registration algorithms. We have also incorporated this technique to a registration-based nonuniformity correction (NUC) framework, indicating that our registration technique is able to estimate motion parameters reliably, leading to satisfactory NUC result.

1. Introduction

Image registration is the process of establishing point-to-point correspondence between two images of the same scene [1,2]. This process is commonly used in infrared imaging systems, such as electronic stabilization of sensors, image fusion, multi-frame super-resolution and nonuniformity correction in infrared focal-plane arrays (IRFPA) [3–9]. In many situations, the performance of algorithms that employ image registration information depends heavily on the accuracy of the shift estimates. However, little attention has been devoted to the registration methods for infrared images in which fixed-pattern noise (FPN) rather than temporal noise is the dominant noise component [4,5]. FPN is perceived as a superimposed pattern that is approximately constant for all image frames. Almost all registration methods require the assumption that the noise in observed images is both spatially and temporally independently distributed [1,2]. The precondition, however, is usually impractical for infrared images especially when they are deteriorated by FPN. Under these circumstances, the performance of these techniques will degrade significantly.

FPN can be reduced by calibrating the sensor by means of imaging target scenes with uniform intensities [10]. It can also be reduced from sequences of video by post-processing algorithms, i.e., scene-based nonuniformity corrections (NUC) [6–9]. However, some of these methods inherently rely on accurate image registration of the raw video. These registration-based techniques can recover the clean scene by analyzing a small number of image frames, using the idea that each detector should have an identical response when observing the same scene point over time. Clearly, the performance of these registration-based nonuniformity methods is often sensitive to the accuracy of registration. If the level of the FPN is high relative to the true scene, then a registration algorithm may mistakenly attempt to register the fixed pattern in the FPN-dominated image while ignoring the motion in the salient true scene. Considering this contradiction, it is therefore very desirable to have a registration algorithm that is tolerant to FPN.

There are many existing shift estimation algorithms for motion estimation between frames. The two-dimensional (2-D) cross-correlation is one of the most commonly used techniques [11]. To improve the performance of these traditional registration techniques, a simple idea is to first blurring each image using spatial low-pass filter, then the registration is performed on the obtained images. This scheme can perform well when the level of FPN is low to moderate. When the level of FPN is relatively high or the FPN mainly exists in the low-spatial frequency domain, the effect of the spatial low-pass filter is very limited. Cain et al. [5] employed a projection-based registration technique which projects each two-dimensional image into two one-dimensional vectors through averaging each image across its rows and columns, resulting in vertical and horizontal image vectors, respectively. It achieves improved performance over the traditional 2-D cross-correlation based techniques in the presence of FPN due to the inherent averaging in the projection. But this method assumes the values of FPN to be independent and identically distributed random variables. Unfortunately, real noise patterns of IRFPA show greatly spatially correlations (such as grids and stripes) [12,13] and they do not fit well with this spatially unstructured model. The real structured FPN may not be well cancelled through averaging

* Corresponding author.
E-mail address: surpasszuo@163.com (C. Zuo).

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each rows and columns, thereby leading to significant performance deterioration.

In view of this, we propose a new technique to address the problem of subpixel registration for infrared images under conditions of FPN. We are interested in investigating the information contained in the Fourier domain and the proposed method is motivated by the observation that the auto-power spectrum of FPN can be cancelled in the difference of the cross-power spectrum of two discrete shifted images while the shift information is well preserved. By deriving an exact model for the phase of the cross-power spectrum difference, we show that this phase matrix is a two-dimensional binary tripe signal and the period of the square signal along each axis determines the shifts along corresponding axis. This in particular leads to a simple solution directly from the phase-difference matrix through transforming its discontinuities to Hough domain. The performance of the proposed method is evaluated with infrared images with both simulated and real structured FPN, showing significantly precise and reliable translation estimates even under a high level of FPN.

The rest of this paper is organized as follows. In Section 2, the problem of image registration in the presence of FPN is formulated. In Section 3, the proposed method is explained and developed. In Section 4, experiential results are given In Section 5, conclusions are drawn.

2. Problem formulation

Let s be the original image, and $f_i(i=1,2)$ be two images that are shifted versions of s:

$$f_i(x,y) = s\left(x+\delta_{x,i}, y+\delta_{y,i}\right), i=1,2 \tag{1}$$

where $(\delta_x, \delta_y) = (\delta_{x,2}-\delta_{x,1}, \delta_{y,2}-\delta_{y,1})$ is the relative translations between the image pair. In the absence of noise and aliasing, the shift property of Fourier transform gives:

$$\hat{f}_1(u,v) = \hat{f}_2(u,v)e^{-j\left(u\delta_x+v\delta_y\right)} \tag{2}$$

where $\hat{f}_i$ is the Fourier transform of f_i and (u, v) are the Fourier domain coordinates. To identify (δ_x, δ_y), one computes a normalized cross-power spectrum between $\hat{f}_1$ and $\hat{f}_2$

$$\hat{c}(u,v) = \frac{\hat{f}_1(u,v)\hat{f}_2(u,v)^*}{\left|\hat{f}_1(u,v)\hat{f}_2(u,v)^*\right|} = e^{-j\left(u\delta_x+v\delta_y\right)} \tag{3}$$

where the hat sign as usual indicates the Fourier transform and the asterisk stands for the complex conjugate. Once computed, the approach cited in the literature [14] is to compute the inverse Fourier transform of $\hat{c}(u,v)$ and a Dirac delta function can be recognized as an intensity peak, which can be found by simply scanning for the global maximum value. The coordinate of this peak corresponds directly to the translation vector (δ_x, δ_y).

In most infrared imaging applications, noise exists in the captured images up to a certain level. In such conditions, the images $f_i(i=1,2)$ in Eq. (1) should be remodeled as

$$f_1(x,y) = s\left(x+\delta_{x,1}, y+\delta_{y,1}\right) + o(x,y) + n_1(x,y) \tag{4}$$

and

$$f_2(x,y) = s\left(x+\delta_{x,2}, y+\delta_{y,2}\right) + o(x,y) + n_2(x,y). \tag{5}$$

where $o(x, y)$ stands for the FPN which is assumed be fixed between two observed images and signal independent. Note that we do not take the assumption that the FPN is spatially independent. This is in agreement with most observations that FPN are indeed spatially structured distributed [12,13]. The term n_1 and n_2 correspond to the additive temporal noise, which are assumed to be mutually independent. The FPN and additive temporal noise are also assumed mutually independent. It is noted that these conditions are valid in general applications. According to this model, the cross-power spectrum can be expressed as:

$$\begin{aligned} S_{f_1f_2}(u,v) = \hat{f}_1(u,v)\hat{f}_2(u,v)^* &= \hat{s}(u,v)\hat{s}^*(u,v)e^{-j\left(u\delta_x+v\delta_y\right)} \\ &+\hat{s}(u,v)\hat{o}^*(u,v)e^{-j\left(u\delta_{x,1}+v\delta_{y,1}\right)} + \hat{s}(u,v)^*\hat{o}(u,v)e^{j\left(u\delta_{x,2}+v\delta_{y,2}\right)} \\ &+\hat{s}(u,v)^*\hat{n}_2(u,v)e^{j\left(u\delta_{x,1}+v\delta_{y,1}\right)} + \hat{s}(u,v)\hat{n}_2^*(u,v)e^{j\left(u\delta_{x,2}+v\delta_{y,2}\right)} \\ &+\hat{n}_1(u,v)\hat{o}^*(u,v) + \hat{n}_2^*(u,v)\hat{o}(u,v) + \hat{o}(u,v)\hat{o}^*(u,v) \\ &+\hat{n}_1(u,v)\hat{n}_2^*(u,v) = \hat{s}(u,v)\hat{s}^*(u,v)e^{-j\left(u\delta_x+v\delta_y\right)} + \hat{o}(u,v)\hat{o}^*(u,v). \end{aligned} \tag{6}$$

Whitening the magnitude is normalized to unity for all frequencies of the cross-power spectrum. In this case, the image data is not cancelled out in the normalized (whiten) cross-power spectrum

$$\hat{c}(u,v) = \frac{S_{f_1f_2}(u,v)}{\left|S_{f_1f_2}(u,v)\right|} = \frac{\hat{s}(u,v)\hat{s}^*(u,v)e^{-j\left(u\delta_x+v\delta_y\right)} + \hat{o}(u,v)\hat{o}^*(u,v)}{\left|\hat{s}(u,v)\hat{s}^*(u,v)e^{-j\left(u\delta_x+v\delta_y\right)} + \hat{o}(u,v)\hat{o}^*(u,v)\right|}. \tag{7}$$

In such circumstances, inverse Fourier transform of $\hat{c}(u,v)$ is no longer a Dirac delta function (Dirichlet kernel in the discrete case

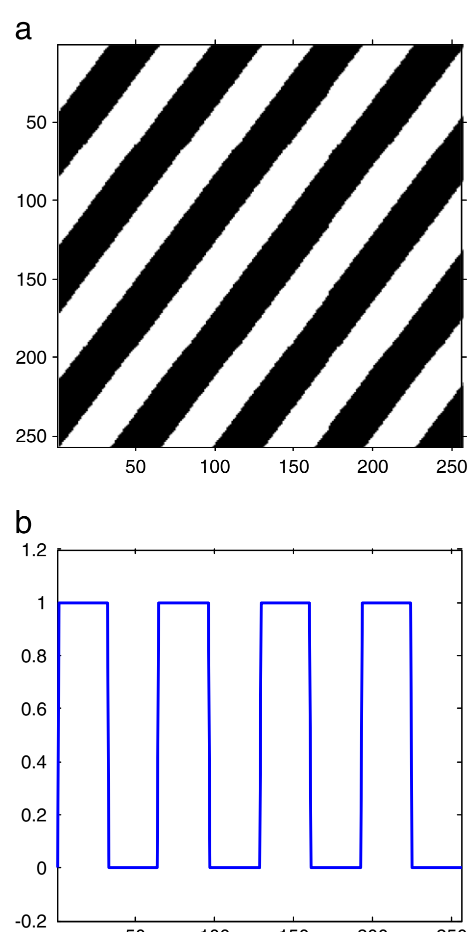

Fig. 1. (a) Phase matrix of discrete cross-power spectrum difference corresponding to shifts of (4,3) pixels, (b) one row of the phase-difference matrices shown in (a).