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Multispectral and panchromatic image fusion using a joint spatial domain and transform domain for improved DFRNT

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ABSTRACT

The use of traditional spatial domain fusion methods such as intensity-hue-saturation (IHS) and principal component analysis (PCA) achieve good spatial quality but often lead to spectral distortion. Use of discrete fractional random transform (DFRNT) fusion, which is a transform domain method proposed by the authors before, can maintain the high spectral information. Hence, in this paper we propose using the respective advantages of DFRNT and IHS or PCA, via combined IHS-DFRNT and PCA-DFRNT approaches to obtain good spectral quality and high spatial quality, which is also for improved DFRNT method. At the same time, instead of fusion in the spatial domain or the transform domain, respectively, as in the conventional methods, the proposed IHS-DFRNT and PCA-DFRNT approaches are fused in a kind of joint spatial domain and transform domain. Moreover, different random distributions of DFRNT produce different fusion results which can meet different application demands. The fused images are found to preserve both the spectral information of the multispectral image and the high spatial information of the panchromatic image. Especially, the proposed combined methods are much faster and keep better comprehensive information than DFRNT. Objective quantitative evaluation indexes are also used to illustrate the effectiveness of the proposed methods.

1. Introduction

In a remote sensing image fusion process, a high spectral and low spatial resolution multispectral (MS) image with a high spatial resolution panchromatic (PAN) image are fused to produce a high spectral and high spatial resolution image [1–7]. Therefore, the major objective of image fusion is to generate a high spatial resolution MS image. With the development of sensor technology, the numbers of available high spatial resolution images are increasing; however, image fusion is still an important and popular method to interpret the data to obtain a more suitable image for a variety of applications, such as visual interpretation and digital classification. For human visual perception and further image processing, both detailed textures and color information of surface features are indeed important. However, due to the limitation of satellite technology, no one sensor can give both types of information for any one scene, which affects the further application of imagery. Hence, image fusion is an effective approach to combine these types of information.

Various fusion algorithms have been proposed. They can be broadly classified into spatial domain methods and transform domain methods according to the domain in which the fusion is performed. The spatial domain methods usually generate a fused image in which each spatial pixel is determined from a set of spatial pixels from the input sources, such as this is done currently in the intensity-hue-saturation (IHS) method [8–10] or the principal component analysis (PCA) [11–13] method. The transform domain methods convert the input images into a common transform domain, such as a wavelet domain [2,14–16], a pyramid domain [17] or a discrete fractional random transform (DFRNT) domain [18]. Fusion is then applied by combining their transform coefficients.

The IHS method converts three MS bands from red–green–blue (RGB) color space into IHS space to separate the spatial component, which is the intensity (I) component, from the spectral components, which are hue (H) and saturation (S) components. After replacing the I component with a PAN image, the merged result is converted back into RGB space. All of these fusion procedures are performed in the spatial domain. Although IHS method can preserve the high spatial information of the PAN image, it severely distorts the spectral information [19]. Actually the I component still has some spectral information, but that information is totally replaced during the

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further processing. The procedures of PCA method are similar to those of IHS, except that the first principal component (PC1) represents the spatial information and PCA can fuse more than three bands. The performance of PCA is similar to that of IHS, and moreover, PCA also usually introduces distortion to the spectral information.

The DFRNT method firstly transforms both MS and PAN images to the DFRNT domain. In DFRNT domain, high amplitude spectrum (HAS) and low amplitude spectrum (LAS) components carry different information from the original images and different fusion rules are adopted in HAS and LAS components, respectively. Here, performing fusion in a transform domain is an indirect change of the original image simultaneously based on spatial image features and different transform spectrum distribution features. The fused image is observed to preserve both the spectral information of MS and the spatial information of PAN. Compared to the IHS method, the DFRNT method preserves spectral information more effectively but spatial information less effectively. The low spectrum distribution obtained can be attributed to the fact that the spectrum distribution of DFRNT is random and dispersive [18].

In this paper, our motivation is to combine DFRNT and IHS or PCA to generate the fused image with both high spectral quality and high spatial quality. Compared to the DFRNT method proposed by authors before, the proposed IHS-DFRNT and PCA-DFRNT methods can obtain higher spatial quality and faster speed, since the I and the PC1 of MS have been extracted previously and then are fused with PAN in the DFRNT domain. In DFRNT method, each and every MS band needs to be transformed to the DFRNT domain. In contrast, in the proposed methods, just the I or PC1 of MS, equivalent to only one MS band, needs to be transformed to the DFRNT domain. In other hand, since the I component and the PC1 component of MS still have some spectral information, we further decompose I and PC1 into low frequency and high frequency components to fuse to get high spectral quality. The proposed IHS-DFRNT and PCA-DFRNT methods are the improved DFRNT method versions. DFRNT transform had been proposed and was first introduced in the fusion field by the authors, now the improved DFRNT fusion is worthy of study.

Meanwhile, the proposed IHS-DFRNT and PCA-DFRNT methods are done using the joint spatial domain and transform domain, instead of fusion in spatial domain or transform domain, respectively, as in the conventional way. The proposed methods include fusion of the spatial domain in the beginning and final steps and fusion of the transform domain in the intermediate steps. Previously reported combinations of the IHS and wavelet methods and of the PCA and wavelet methods [20,21] were also done using both the spatial domain and the transform domain. However in this paper, the DFRNT domain is very different from the wavelet domain, even though they both are types of transform domains. In the DFRNT domain, there is no intuitive correspondence to the spatial information of the image; instead, it just has the transform spectrum information. On the other hand, in the wavelet domain, one can see an approximate spatial image and the detailed edges of the image. The specific difference between the wavelet domain and the DFRNT domain is shown in Fig. 1.

The rest of this paper is organized as follows. The proposed methods are described in Section 2. Section 3 provides the experimental results including test data, fusion methods for comparison, evaluation criteria and performance analysis. The conclusion is drawn in Section 4.

2. The proposed fusion method

2.1. DFRNT and its properties

DFRNT originates from the discrete fractional Fourier transform (DFrFT), which is a joint space-frequency transform. The transform

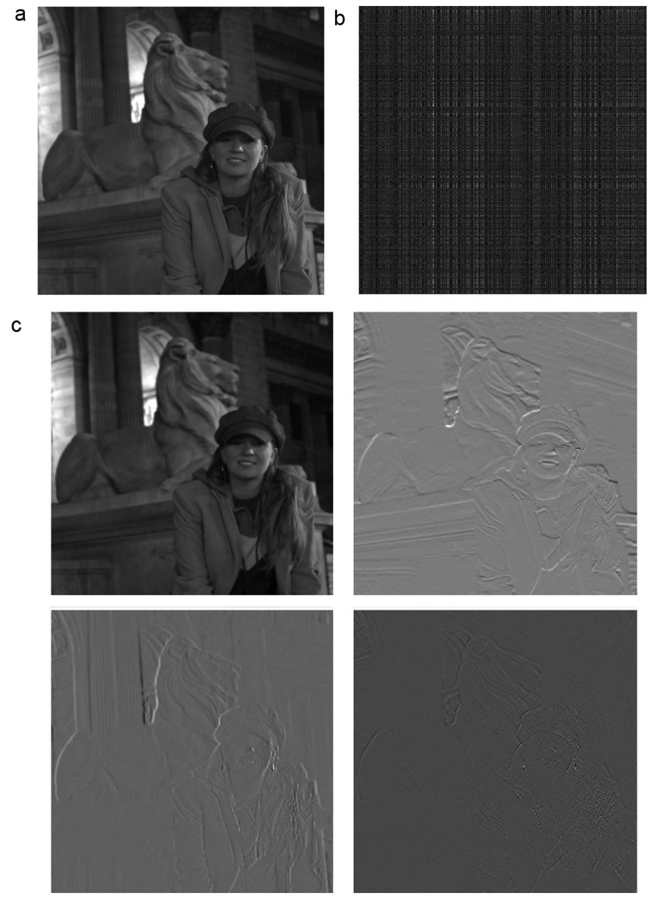

Fig. 1. Illustrations of the differences between the wavelet and DFRNT transform domains: (a) spatial image; (b) DFRNT transform domain; (c) wavelet transform domain.

coefficients of DFrFT represent the contribution of each basis function at each frequency, thus DFrFT has the exact transform spectrum domain and the corresponding spatial image can be obtained only after the inverse DFrFT transform. DFrFT can clearly display features of signals which are difficult to be displayed in spatial domain. DFrFT converts the grayscale distribution of an image into its frequency distribution; moreover, the perfect frequency resolution indicates the extent of change in gray scale. DFRNT has the most excellent mathematical properties as DFrFT in addition to the inherent randomness. Therefore, performing fusion in such transform domain is an indirect change of the original image simultaneously based on spatial image features and different spectrum distribution features.

For discrete transforms, the kernel matrix is key, which can be expressed as the product of eigenvector and eigenvalue matrices through eigendecomposition. DFRNT has the same eigenvalues as DFrFT, but with random eigenvectors. DFRNT for two-dimensional signal $\mathbf{x}$ can be expressed as

$$\mathbf{X}_{\mathbf{R}(\alpha)} = \mathbf{R}^{\alpha}\mathbf{x}\left(\mathbf{R}^{\alpha}\right)^{t}. \quad (1)$$

The kernel transform matrix $\mathbf{R}^{\alpha}$ is written as

$$\mathbf{R}^{\alpha} = \mathbf{V}\mathbf{D}^{\alpha}\mathbf{V}^{t}, \quad (2)$$

where $\mathbf{D}^{\alpha}$ is the diagonal matrix generated by eigenvalues $\left\{\exp\left(-2i\pi n\alpha/T\right) : n = 0, 1, 2, \ldots, N-1\right\}$ of DFRNT, α is the fractional order of DFRNT, $\mathbf{V}$ is the eigenvector matrix, $\boldsymbol{T}$ is the period of eigenvalues with respect to the fractional order and t expresses the transpose. The randomness of DFRNT comes from the matrix $\mathbf{V}$, which is generated by eigenvectors of a symmetric random matrix.