Biorthogonal Wavelets-based Landsat 7 Image Fusion

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Abstract : Currently available image fusion methods are not efficient for fusing the Landsat 7 images. Significant color distortion is one of the major problems. In this paper, using the well-known wavelet based method for data fusion between high-resolution panchromatic and low-resolution multispectral satellite images, we performed Landsat 7 image fusion. Based on the experimental results obtained from this study, we analyzed some reasons for color distortion. A new approach using the biorthogonal wavelets based method for data fusion is presented. This new method has reached an optimum fusion result - with the same spectral resolution as the multispectral image and the same spatial resolution as the panchromatic image with minimum artifacts.

Keywords : Image Fusion, Multiresolution analysis, Biorthogonal Wavelets, Landsat 7 image

1. Introduction

In many remote sensing and mapping applications, the fusion of high-spectral but low spatial resolution multispectral and low-spectral but high spatial resolution panchromatic satellite images is a very important issue.

Many image fusion techniques and software tools have been developed. The well-known methods are, for example, the IHS (Intensity, Hue, Saturation), PCA(Principal Components Analysis), arithmetic combination based fusion, and wavelet based fusion[1]. Most techniques have been developed based on the fusion of the SPOT pan with other multispectral images, such as Lansat TM and SPOT HRV XS. However, a common problem associated with the available techniques is the color distortion of the fused images.

To date, well-fused satellite images with SPOT or IRS panchromatic band as a high-resolution input have been presented in some publications; however, publications on well-fused Landsat 7 images have been rarely seen. A major reason is the change of the Landsat 7 panchromatic spectral range. Different from SPOT panchromatic and IRS panchromatic images, the wavelength of Landsat 7 panchromatic images was extended from visible to near infrared range. This change makes the grey value relationship of a Landsat 7 panchromatic image significant different from that of a SPOT panchromatic or IRS panchromatic image. For example, vegetation areas in the SPOT panchromatic image appear darker than pavement areas. However, they appear brighter than pavement areas in the Landsat pan image because of the influence of near infrared content. Therefore, it is not a wonder that conventional fusion methods, which have been successful for the fusion of SPOT panchromatic and other multispectral images, cannot effectively fulfill the fusion of the new images.

Assessment of the quality of the fused images is another important isuue. Wald *et al.* proposed an approach with criteria that can be used for evaluating the spectral quality of the fused satellite images[2].

If the objective of image fusion is to construct synthetic images that are closer to the reality they represent, then, according to the criteria proposed by Wald *et al.*, IHS and PCA fusion methods meet this objective[1]. However, one limitation of such methods is some distortion of spectral characteristics in the original multispectral images. Recently developments in wavelet analysis provide a potential solution to these drawbacks. For example, Nunez *et al.* developed an approach to fuse a high-resolution panchromatic image with a low-resolution multispectral image based on wavelet decomposition[3]. Ranchin and Wald designed the ARSIS concept for fusing high spatial and spectral resolution images based on the multiresolution analysis of two-band wavelet transformation[1]. However, the well-known wavelet based methods, which have been successful for the fusion of SPOT panchromatic and other multispectral images, are not efficient for fusing the Landsat 7 images. Moreover, the fused image appears like a result of a high-pass filtering fusion, e.g., the color seems not being smoothly integrated into the spatial features.

In this paper, a new technique using the biorthogonal wavelets have been developed. This technique can effectively fuse the Landsat 7 images. In this approach, the color distortion can be reduced to a certain extent. In addition, this method overcome Landsat 7 image fusion's weaknesses.

The structure of this paper is as follows. The next section discusses the theoretical basis and transformation characteristics of the biorthogonal wavelets. Then, a new image fusion approach for Landsat 7 pan and multispectral images based on the biorthogonal wavelets is presented. This is followed by a discussion of the image fusing experiments. Next, the experimental results are analyzed. Furthermore, the proposed method is compared with the previous methods developed for image fusion, such as the orthonormal wavelet method and the IHS method.

2. Biorthogonal wavelets

1) Multi-resolution analysis

Wavelets are functions in $L^2(R)$ determined from a basic wavelet function by dilations and translations. They are used for representing the local frequency content of functions. The basic wavelet should be well localized in general, and the wavelet should have zero mean[4]. The basic method to construct a wavelet is multi-resolution analysis.

A multi-resolution analysis is an increasing sequence $\{V_j\}_{j\in Z}$, which approximates $L^2(R)$, i.e.,

$$\{0\}\cdots\subset V_{-1}\subset V_0\subset V_1\subset\cdots L^2(R), \quad (1)$$

and satisfies the following property:

$$f(x)\in V_j \Leftrightarrow f(2x)\in V_{j+1}. \quad (2)$$

There exists a scaling function $\varphi(x)$ in V_0 such that the set $\{\varphi(x-k)\}_{k\in Z}$ is an orthonormal basis of V_0. The function $\varphi(x)$ satisfies the scaling equations

$$\varphi(x)=\sum_{k\in Z} c_k\varphi(2x-k), \quad (3)$$

where Z is an integer set, and $\{c_k\}$ is a set of scaling function coefficients which satisfy the following filter equation:

$$H(z)=\frac{1}{2}\sum_{k\in Z} c_k z^k. \quad (4)$$

Using the scaling function, we can obtain the wavelet function $\psi(x)$ that satisfy the following scaling equations

$$\psi(x)=\sum_{k\in Z} d_k\varphi(2x-k), \quad (5)$$

2) Biorthogonal wavelets

A multi-resolution analysis for the biorthogonal wavelet transforms, similar to the orthonormal wavelet transformation , exists. But, in addition to Equation (1), we use the following equations:

$$\{0\}\cdots\subset V_{-1}\subset V_0\subset V_1\subset\cdots L^2(R), \quad (6)$$

and $$\{0\}\cdots\subset \tilde{V}_{-1}\subset \tilde{V}_0\subset \tilde{V}_1\subset\cdots L^2(R). \quad (7)$$

In addition to Equation (3), there exists a dual scaling function $\tilde{\varphi}(x)$ in $\tilde{V}_0$ such that

$$<\varphi(x-k),\tilde{\varphi}(x-l)>=\delta_{k,l}.$$

Similarly, the function $\tilde{\varphi}(x)$ satisfies the scaling equations

$$\tilde{\varphi}(x)=\sum_{k\in Z}\tilde{c}_k\tilde{\varphi}(2x-k). \quad (8)$$

Continuing to parallel the construction of the orthogonal wavelets, we also can obtain the wavelet and the dual wavelet as

$$\psi(x)=\sum_{k\in Z} d_k\varphi(2x-k), \quad (9)$$

$$\tilde{\psi}(x)=\sum_{k\in Z}\tilde{d}_k\tilde{\varphi}(2x-k). \quad (10)$$

The biorthogonal wavelet systems generalize the classical orthogonal wavelet systems. They are more flexible and generally easy to design. One of the main reasons to choose biorthogonal wavelets over the orthogonal ones is symmetric. Symmetric wavelets and scaling functions are possible in the framework of biorthogonal wavelets. However, the orthogonality no longer holds in biorthogonal wavelet systems. However, that is the near orthogonal system.

3. Experimental Study and Analysis

As an experimental study, the biorthogonal wavelets based image fusion method was applied to the 15m resolution Landsat 7 panchromatic image and three 30m resolution multispectral images.

1) Visual analysis

From the fused image in Fig.1, it should be noted that both the spatial and the spectral resolutions have been enhanced, in comparison to the original images. The spectral information in the original panchromatic image has been increased, and the structural information in the original multispectral images has also been enriched. Hence, the fused image contains both the structural details of the higher spatial resolution panchromatic image and the rich spectral information from the multispectral images. Compared with the fused result in Fig.1 of the orthonormal wavelet, the fused result by the biorthogonal wavelets has a better visual effect in Landsat 7 image fusion.

Fig.1. Fused images by using (a) the biorthogonal wavelet transformations, (b) the orthonormal wavelet transformation, and (c) IHS method, respectively.

2) Quantitative analysis

In addition to the visual analysis, we extended our investigation to a quantitative analysis. The experimental result was analyzed based on the combination entropy, the standard deviation, the mean gradient, and the correlation coefficient, as used in other studies such as Wald et al.(1997), Sun et al.(1998), and Li et al.(1998).

Table 1 presents a comparison of the experimental results of image fusion using the biorthogonal wavelets, the orthonormal wavelet, and IHS methods in terms of combination entropy, the standard deviation, the mean gradient, and the correlation coefficient.

The combination entropy(C.E.) represents the property of combination between images. The larger the combination entropy of an image, the richer the information contained in the image. In Table 1, the combination entropy of the biorthogonal wavelets based image fusion is greater than these of other methods. Thus, the biorthogonal wavelets method is better than the orthonormal wavelet and IHS methods in terms of combination entropy.

The standard deviation globally indicates the level of error at any pixel. In Table 1, the standard deviation of the biorthogonal wavelets based image fusion is more close to the standard deviation of original images than these of other methods. That is, The orthonormal wavelet and IHS methods have much more distortion of the spectral characteristic of the image. This is one of the main advantages of using the biorthogonal wavelets method.

Table 1. A comparison of Image fusion by the biorthogonal wavelets, orthonormal wavelet, and IHS methods.

Method	C.E.	S.D	M.G.	C.C
Original Images (M1,M2,M3)	0.4098	45.1023 42.9128 45.7804	13.8520 15.2458 17.7958	— — —
Image fused by the biorthogonal W.Ts (F1,F2,F3)	0.5031	46.3894 44.4229 47.2941	13.6139 14.0545 15.5207	0.9272 0.8151 0.8434
Image fused by the orthonormal W.T (F1,F2,F3)	0.4065	60.2150 55.9715 56.3786	27.0195 26.7359 26.2708	0.9117 0.8131 0.8462
Image fused by IHS method (F1,F2,F3)	0.3715	60.2319 57.0658 59.2424	17.2141 17.5267 18.2848	0.9631 0.9352 0.9517

The mean gradient(M.G.) reflects the contrast between the details variation of pattern on the image and the clarity of the image. And the correlation coefficient between the original and fused image shows the similarity in small size structures between the original and synthetic images. In Table 1, The mean gradient and the correlation coefficient of IHS method are greater than these of the biorthogonal wavelets method. As previously stated, if the objective of image fusion is to construct synthetic images that are closer to the reality they represent, then IHS fusion method meet this objective very well. But, if the objective of image fusion is the spectral quality of fused images, then the biorthogonal wavelets fusion method is much more than IHS method. Moreover, the currently orthonormal image fusion methods, which have been successful for the fusion of SPOT panchromatic and other multispectral images, are not efficient for fusing the Landsat 7 images. However, based on the experimental results obtained from this study, the biorthogonal wavelets based image fusion method is very efficient for fusing the Landsat 7 images. This is the main reason to choose biorthogonal wavelet transformations over the orthonormal ones.

4. Conclusions

We have presented a newly developed method based on the biorthogonal wavelet transformations for fusing Landsat 7 images. In this paper, an experimental study was conducted by applying the proposed method, and also other image fusion methods, for fusing Landsat 7 images. A comparison of the fused image from the orthonormal wavelet, and IHS method was made. Based on the experimental results respecting the four indicators – the combination entropy, the standard deviation, the mean gradient, and the correlation coefficient, the proposed method provides a better result than those based on the orthonormal wavelet and IHS methods.

Theoretically, one of the main reasons to choose biothogonal wavelets is the fact that biorthogonal filters are symmetric and more smooth. This is the reason why the biorhogonal wavelets based image fusion method is very efficient for fusing Landsat 7 images. In particular, the wavelength of IKONOS and QuickBird panchromatic images was extended from visible to near infrared range the same as Landsat 7 pan. Therefore, this technique can effectively fuse the new satellite images, e.g., IKONOS, QuickBird pan.

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