An Approach to Fuse IKONOS Images by Wavelet Transformation

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Abstract

This paper develops an approach to fuse 1-meter resolution spatial panchromatic and 4-meter resolution multi-spectral IKONOS images. The approach is based on the characteristics of four-band wavelet transformation. The experiment shows that the fused images based on four-band wavelet method contain with not only high spatial resolution but also rich spectral characteristic.

Key words: IKONOS images, Fusion, Four-band wavelet transforamtion

1. Introduction

In the recent years, launching high-resolution satellites such as IKONOS and others has opened a new area for remote sensing and its application. IKONOS can supply 1-meter resolution spatial panchromatic and 4-meter resolution multi-spectral images. With a 1-meter resolution panchromatic IKONOS image, detailed geometric features can be easily recognized, while 4 meter multi-spectral IKONOS image contains spectral information. The capabilities of the images can be enhanced if the advantages of both types of IKONOS images are integrated on one image, which is very helpful for many areas such as image segment. The major solution to approach this target is image fusion method.

There have been many studies on the image fusion [1--3]. Many of these methods have been widely used, for example, IHS color model, PCA method, HLS fusion method, COS fusion method and HSV (Hue, Saturation and Value) method [4 -- 6]. Furthermore, wavelet analysis provides an alternative solution and has been one of the reach focuses among the imagery fusion. For example, Sun *et al.* studied the fusion of remotely sensed imageries based on wavelet features [7]. Shi and Zhu et al studied the fusion of SPOT panchromatic and multi-spectral images by three-band wavelet transformation [8].

In this paper, we will develop an approach to fuse 1-meter resolution panchromatic and 4-meter resolution multi-spectral images from IKONOS based on band-band wavelet transformation.

This paper is organized as follows. Section 2 discusses the transformation characteristics of multi-band wavelet. Section 3 presents a new image fusion approach for IKONOS images based on the four-band wavelet. Section 4 reports an image fusing experiments. Conclusions are given in the last section.

2. The transformation Characteristics of multi-band wavelet

Multi-band wavelet is a branch of the wavelet analysis and has been attracted as a research focus in recent years. Both theoretical researches and several application studies of multi-band wavelet had been performed[9-11]. However, application of this technology to remotely sensed image fusion is few.

2.1 Multi-scale analysis of multi-band wavelet

Wavelets are functions in a space $L^2(R)$ from a basic wavelet function by dilations and translations. They are used to represent the local frequency content of the functions. The basic wavelet should be well localized, and a wavelet should have zero mean [9]. The basic method for constructing a wavelet is by a multi-scale analysis.

A multi-scale analysis is an increasing sequence $\{V_j\}_{j \in Z}$ that approximates $L^2(R)$

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

and it satisfies the following property:

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

In a multi-band wavelet, taking a specific M-band wavelet where M is a positive integer, as an example, there are M-1 wavelet functions $\{\psi_s(x) \mid 1 \le s \le M-1\}$ for a scaling function $\varphi(x)$. $\varphi(x)$ and $\{\psi_s(x) \mid 1 \le s \le M-1\}$ satisfy the following scaling equations

$$\varphi(x) = \sum_{k \in Z} c_k \varphi(Mx - k), \quad \psi_s(x) = \sum_{k \in Z} d_k^s \varphi(Mx - k)$$

where $\{d_k^s\}$ is a set of wavelet coefficients, and $\{c_k\}$ is a set of scaling function coefficients which satisfy the following filter equation

$$H(z) = \frac{1}{M} \sum_{k \in Z} c_k z^k$$

H(z), $\varphi(x)$ and $\psi_s(x)$ can be found in [9--10].

A multi-band wavelet ($M > 2$) is superior to two-band wavelet in many aspects, such as compact support and symmetry, especially its decomposition characteristics.

22. Decomposition and reconstruction of multi-band wavelet

By applying the tensor product, two-dimensional orthogonal wavelet bases can be obtained from one-dimensional wavelet bases. Hence, the multi-band orthogonal wavelet decomposition and reconstruction of an image $\{a_{0,k,l}\}$ ($k, l \in Z$) can be obtained. The decomposition formula of M-band wavelet are

$$a_{j+1,k,l} = \sum_m \sum_n c_{m-Mk} c_{n-Ml} a_{j,m,n} ,$$

$$b_{j+1,k,l}^{t,s} = \begin{cases} \sum_m \sum_n c_{m-Mk} d_{n-Ml}^s a_{j,m,n}, & t = 0, 1 \le s \le M-1 \\ \sum_m \sum_n d_{m-Mk}^t c_{n-Ml} a_{j,m,n}, & 1 \le t \le M-1 \\ \sum_m \sum_n d_{m-Mk}^t d_{n-Ml}^s a_{j,m,n}, & 1 \le t, s \le M-1 \end{cases}$$

where j = 0, 1, 2, … . The reconstruction formula is

$$a_{j,k,l} = \sum_m \sum_n c_{k-Mm} c_{l-Mn} a_{j+1,m,n} + \sum_{t,s=0, s+t \ne 0}^{M-1} \sum_m \sum_n d_{k-Mm}^t d_{l-Mn}^s b_{j+1,m,n}^{t,s} .$$

Where j = 0, 1, 2, …… . $\{a_{j+1,k,l}\}$ is the low-frequency portion of the $(j+1)^{th}$ level M-band wavelet decomposition of the image $\{a_{j,k,l}\}$, and $\{b_{j+1,k,l}^{t,s}\}$ is the high-frequency portion of the $(j+1)^{th}$ level. Hence, by applying the M-band wavelet transformation, the image is decomposed into one low-frequency portion and ($M^2 - 1$) high-frequency portions. If the low-frequency portion of wavelet transformation is further decomposed, the following level wavelet decomposition can be obtained. By an inverse wavelet transformation, the original image can be reconstructed.

In the multi-band wavelet, when $M = 2$, we have the two-band wavelet. In fact, the most of the applications of wavelet for image processing in the past studies were based on the two-band wavelet. When $M = 4$, we have the four-band wavelet which will be used to develop an approach of fusing IKONOS images in this paper.

Figure 1 gives the Lenna image and its two-band wavelet decomposition and the four-band wavelet decomposition.

Figure 1. Lenna images and its wavelet decomposition (a) the original Lenna image, (b) two-band wavelet decomposition and (c) four-band wavelet decomposition.

The ratio of the spatial resolution between 1-meter resolution panchromatic and 4-meter multi-spectral IKONOS images is four. We thus propose to fuse the two types of IKONOS images using the four-band wavelet transformation.

3 The fusion method for IKONOS images based on Multi-band wavelet transformation

3.1 Fusion method

It is known that the spatial and spectral features of a ground area are shown very differently on different remotely sensed images. According to the image analysis in frequency domain, the difference in low-frequency portion, for different images corresponding to the same ground area, is not very high. However, that for the high-frequency portion can be very high. A wavelet transformation is with the characteristics of decomposition of frequency. Therefore, wavelet can be used to form a basis for image fusion.

By four-band wavelet transformation, the developed method in this paper can fuse IKONOS 1-meter resolution panchromatic and 4-meter resolution multi-spectral images. And the basic procedures are followings.

(1) Both a 1-m resolution panchromatic image and 4-m resolution multi-spectral IKONOS images are geometrically registered to each other.

(2) Three new IKONOS panchromatic images P1, P2 and P3 are produced, and whose histograms are specified according to the histograms of multi-spectral images M1, M2 and M3 respectively.

(3) P1, P2 and P3 are decomposed into wavelet transformed images W1, W2 and W3 respectively by applying four-band wavelet. The image size of the low-frequency portion is the same as the multi-spectral IKONS images.

(4) The low-frequency portions of wavelet transformation images W1, W2 and W3 are replaced by multi-spectral IKONOS images (M1, M2 and M3) according some rules respectively. Three new images (I1, I2 and I3) are obtained.

(5) The inverse wavelet transformations are carried out for I1, I2, I3 respectively. Three new images (F1, F2 and F3) are then obtained.

(6) F1, F2 and F3 are compounded into a single fused image F. The spectral information of the original multi-spectral IKONOS images is retained.

3. 2 Fusion experiments

By above proposed image fusion method, a fusion experiment is carried out for 1-meter resolution panchromatic and 4-meter resolution multi-spectral IKONOS images for an area of Hong Kong.

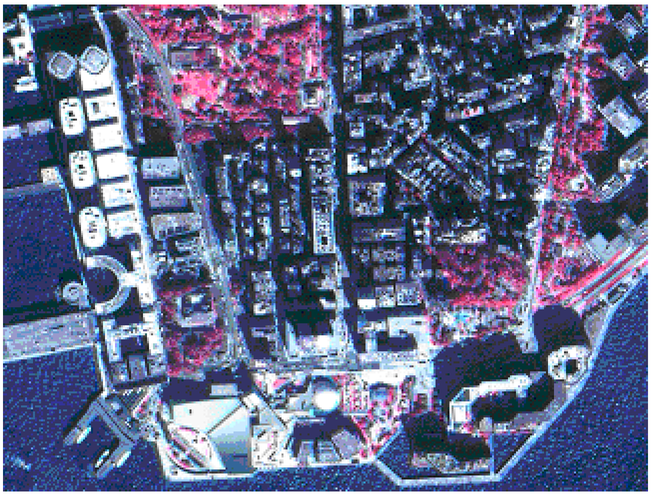

Figure 2. Fused image by four-band wavelet transformation

From the fused image in Figure 2, it is noticed that both spatial and spectral resolutions have been enhanced in comparison with the original images. Spectral information of original panchromatic image has been increased, and structural information of original multi-spectral TM images has also been enriched. Hence, the fused image contained both structural details of the higher spatial resolution panchromatic image and rich spectral information from the multi-spectral IKONOS images as well.

4. Conclusions

This paper presented a newly developed method, which is based on four-band wavelet transformation, for fusing 1-m resolution panchromatic image with 4-m resolution multi-spectral IKONOS images. The experimental result demonstrates that fused image based on four-band wavelet methods contains good spatial and spectral information. The method improves the efficiency of image fusion application, such as for automatic pattern recognition and image segment.

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