STUDY ON DATA FUSION METHODS WITH OPTIMAL INFORMATION PRESERVATION BETWEEN SPECTRAL AND SPATIAL BASED ON HIGH RESOLUTION IMAGERY

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ABSTRACT:

Data fusion methods are often employed to balance contradiction between spectral information and spatial information of remotely sensed images. The fused images formed by an effective data fusion method based on remotely sensed data should have both high spectral information preservation with Low Spatial Resolution (LSR) images and high spatial information preservation with High Spatial Resolution (HSR) image. In this paper, Modification Brovey Transform (MBT) has been proposed so as to fuse either individual band LSR images of high resolution imageries. Three fusion methods, such as Smoothing Filter-based Intensity Modulation (SFIM), Discrete Wavelet Transform (DWT) and MBT have been used to fuse Quickbird images and IKONOS images. Both spectral information preservation and spatial information preservation of the fused images generated by three fusion methods based on two kinds of high resolution imageries have been evaluated by qualitative visual interpretation and quantitative statistical analysis. The evaluation results confirm that the proposed method has optimal spatial information preservation with HSR image in both fusion results. Meanwhile, SFIM fusion method has optimal spectral information preservation with LSR images.

1. INTRODUCTION

At present, the spatial and spectral resolutions of remotely sensed sensors are highly correlated factors. In general, the sensor with a higher spatial resolution (broader spectral range) is often achieved at the cost of a lower spectral resolution and vice-versa. On the same satellite or airplane platform, a panchromatic sensor covers a broader spectral range, while a multi-spectral sensor covers a narrower spectral range. With the development of technology, many high resolution sensors, such as Quickbird and IKONOS, have been successfully launched. The sensors of Quickbird and IKONOS both can provide four bands multi-spectral (MS) images and one band panchromatic (PAN) image with resolution ration 1:4. Four bands MS images provide more spectral information than PAN image and PAN image provides higher spatial information compared with MS image. Both spectral information and spatial information of remotely sensed images are very important for most remote sensing application. To take advantage of the spectral information of MS images and high space information of PAN image, data fusion techniques are often employed to generate fused images with high spectral and spatial quality simultaneously. Data fusion based on remotely sensed images is called image fusion. However, during the processing of image fusion, some useful information (spectral and spatial) will be lost, so an effective image fusion method should have optimal information preservation between spectral and spatial.

Many image fusion techniques have been proposed to fuse low spatial resolution (LSR) images, such as MS images, with high spatial resolution (HSR) image, such as PAN image. These image fusion techniques can be divided into three fusion strategies. One strategy is based on RGB space transform, such as intensity-hue-saturation (IHS) (Haydan et al,1982) transform and Brovey transform (BT) (Gillespie et al,1987). These techniques have the limitation that only three bands LSR images are involved. The second strategy is based on spatial filters, such as high-pass filtering (HPT) (Chavez et al,1988) transform, smoothing filter-based intensity modulation (SFIM) (Liu, 2000), and different wavelet transform (WT) (Zhou et al,1998; Nuñez et al,1999; Nencini et al,2007). The techniques belonging to this strategy can be used to fuse either individual band LSR images, independently. The third strategy is based on simple algebraic operation, such as multiplication-transform (MT) (Li et al,2006). It should state that there are no obvious limits between three strategies. For instance, BT belongs to both the first and the third strategies, while HPT belongs to the second and the third strategies. Meanwhile image fusion techniques belonging to different strategies are often used together (Audícana et al, 2004; Chibani et al,2002).

In this paper, Modification BT (MBT) has been proposed so as to fuse either individual band LSR images of high resolution remotely sensed images independently, such as Quickbird or IKONOS. Three fusion techniques, including SFIM, WT and MBT, have been employed to fuse LSR images with HSR image of Quickbird and IKONOS. Both spectral information and spatial information preservation of three fusion methods have been evaluated by qualitative visual interpretation and quantitative statistical analysis.

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2. IMAGE FUSION TECHNIQUES

2.1 Smoothing Filter-based Intensity Modulation

SFIM is spatial domain fusion method based on smoothing low-pass filters. It is defined as:

$$B_{SFIM} = \frac{B_L \times B_H}{B_M} \qquad (1)$$

Where B_L is LSR image, B_H is HSR image, B_M is a simulation image of LSR image, and it derived from B_H image using an average low pass filter.

SFIM can be understood as a LSR image modulated directly by high spatial frequency information and the fused image is independent of the contrast and spectral properties of the HSR image. It is critical for the selection of a low pass filter kernel to generate B_M image. The minimal filter kernel size is decided based on the resolution ration between the higher and lower resolution images (Liu,2000). For example, the minimal filter kernel size should adopt 4×4 filter window for fusing LSR image with HSR image of Quickbird or IKONOS. SFIM-fused images have fine spectral information preservation with the LRS images, but the edges between different features are blurred in SFIM-fused productions (Liu,2000).

2.2 Wavelet Transform

More recently, Discrete WT (DWT) has started playing a role in image fusion. In general, DWT consists of wavelet decomposition (Fig. 1) and reconstruction (Fig. 2). There are following steps in image fusion based on DWT.
1) Selecting biorthogonal wavelet bases used in wavelet decomposition and reconstruction.

2) The selected wavelet bases are applied to decompose LSR and HSR images. After decomposition at any level, the low frequency sub-image (commonly termed “approximation” coefficients) is passed to the next decomposition. High frequency sub-images (termed “horizontal”, “vertical”, and “diagonal”) are retained for reconstruction.

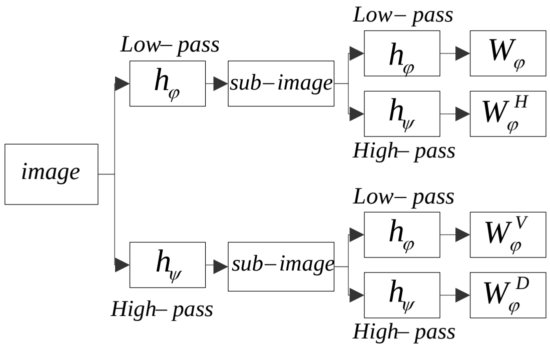


Figure 1. The wavelet decomposition of two-dimensional DWT

W_φ , W_ψ^H , W_ψ^V and W_ψ^D (Fig. 1) are approximation coefficients, horizontal coefficients, vertical coefficients and diagonal coefficients, respectively.

3) The low frequency sub-image of LSR image and the high frequency sub-images of HSR image are selected to generate the fused image by wavelet reconstruction (Fig. 2).

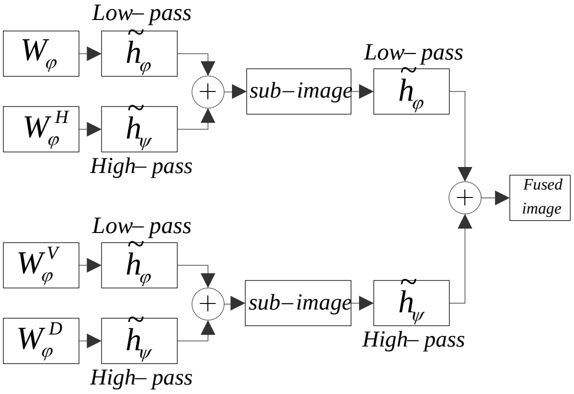


Figure 2. The wavelet reconstruction of two-dimensional DWT

The key issues in DWT are selections wavelet bases, decomposition levels and replacement sub-images. Different selections form different fusion models. Depending on the optimization control, fusion methods based on DWT can better preserve image spectral properties than IHS transform and BT. However, because of more complicated and time-consuming processing and critical requirement for the co-registration accuracy, these techniques are less popular than IHS transform and BT for remote sensing applications which prefer fast interactive processing and real time visualization (Liu,2000).

2.3 Brovey Transform

One of widely used image fusion methods is BT based on chromaticity transform and RGB space transform. It is a simple and efficient technique for fusing remotely sensed images. BT is defined as:

$$\begin{aligned} R_{BT} &= \frac{R}{I} \times B_H, G_{BT} = \frac{G}{I} \times B_H \\ B_{BT} &= \frac{B}{I} \times B_H, I = \frac{R+G+B}{3} \end{aligned} \qquad (2)$$

Where *R*, *G* and *B* are three bands LSR images.

Only three bands LSR images are involved in standard BT. Thus, there are different choices when the total number of LSR images is more than three. For example, there are four different choices in the case of fusing four bands LSR images of Quickbird or IKONOS. To solve the problem, Modification BT (MBT) fusion method based on the principle of BT is introduced in this paper. MBT is defined as:

$$B_{MBTi} = \frac{B_{Li}}{\frac{\sum_{i=1}^{n} B_{Li}}{n}} \times B_H \qquad (3)$$

Where *n* is total number of LSR images.

3. EXPERIMENTT RESULTS AND ANALYSIS

In this section, we consider two different data sets acquired by Quickbird and IKONOS satellite sensors, respectively. The purpose of selecting two types of sensors is to demonstrate that selected fusion methods work for both very high spatial resolution image. In order to assess the effectiveness of the proposed method, MBT is compared with the fusion methods which can also fuse either individual band LSR images, such as SFIM and DWT. Three fusion methods are all achieved on the ERDAS IMAGE 8.7 platform. SFIM and MBT are achieved under spatial modeler. DWT based on ERDAS IMAGE 8.7 platform is a modification of the work of King (King et al,2001) with extensive input from Lemeshewsky (Lemeshewsky,1999a; Lemeshewsky,2002b). The spectral quality and spatial quality of the fused images will be evaluated by the following indexes.

3.1 Information Preservation Evaluation

3.1.1 Spectral Quality of the Fusion Methods: The fused images gain spectral information from LSR images, so, the spectral quality of the fusion methods will be evaluated by the comparing their spectral quality with that of the original LSR images. The comparing is performed by the following indexes.

Spectrum Difference (*SD*) between original LSR images and the fused images.

$$SD = \left| \frac{1}{MN} \sum_{j=1}^{M} \sum_{k=1}^{N} \frac{LSR_{jk} - FUS_{jk}}{LSR_{jk}} \right| \qquad (4)$$

Where *MN* is the total number of pixels of original and fused images, FUS_{jk} is the radiance value of pixel *j* in the *k*th band of the fused image, and LSR_{jk} is the radiance value of pixel *j* in the *k*th band of original LSR image.

The index *SD* can only evaluate the spectral quality of individual band. The spectral *ERGAS* (Wald,2000) index has been selected to estimate the global spectral quality of the fusion methods, and spectral *ERGAS* is defined as:

$$ERGAS = 100\frac{h}{l}\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{RMSE(B_i)^2}{M_i^2}\right)} \qquad (5)$$

Where *h* is the spatial resolution of HSR image, *l* is the spatial resolution of LSR image, *n* is the total number of the fused images, M_i is the mean radiance value of original image and $RMSE(B_i)$ is defined as:

$$RMSE(B_i) = \sqrt{(M_i - FUS_i)^2} \qquad (6)$$

Where FUS_i represents the radiance of the *i*th band fused image.

The lower value of *SD* and spectral *ERGAS* indexes, the higher the spectral quality of the merged images. The values of *SD* and *ERGAS* indexes are zero in ideal condition, and fusion method has optimal spectral information preservation when the values of *SD* and *ERGAS* indexes are closer to zero.

3.1.2 Spatial Quality of the Fusion Methods: The fused images gain spatial information from HSR image, and the spatial quality of the fusion methods will be evaluated by the relationship between the fused images with HSR image using the indicators of Correlation Coefficient (*CC*) and spatial *ERGAS* (Lillo-Saavedra et al,2005). *CC* is got by:

$$CC = \frac{\sum_{i=1}^{M}\sum_{j}^{N}(F(x_i,y_j)-\bar{f})(O(x_i,y_j)-\bar{o})}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(F(x_i,y_j)-\bar{f})^2(O(x_i,y_j)-\bar{o})^2}} \qquad (7)$$

Where *F(x, y)* and *0(x, y)* are the pixel grey values of fused and HSR images respectively, $\bar{f}$ is the mean value of fused image, and $\bar{o}$ is the mean value of HSR image.

Spatial *ERGAS* is similar with spectral *ERGAS*. A spatial *RMSE* index is included in spatial *ERGAS* definition, and spatial *RMSE* is got by:

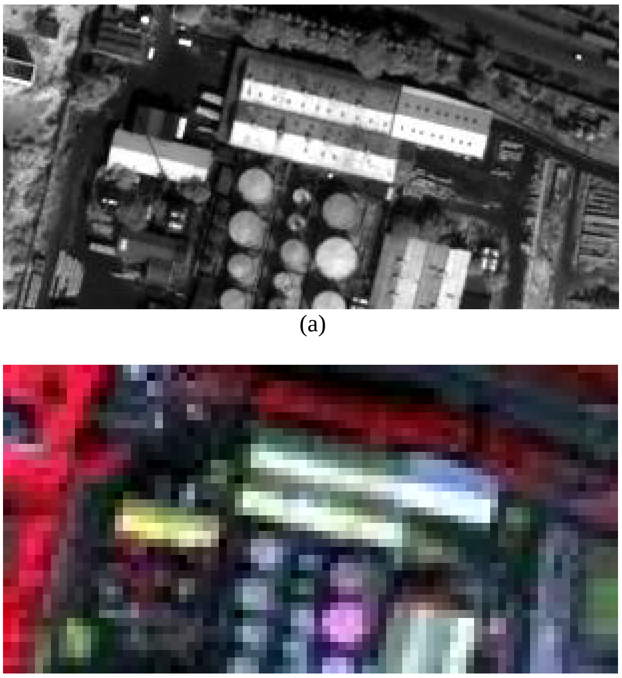
$$RMSE(F_i) = \sqrt{(M_{Fi} - M_{HSR})^2 + (SD_{Fi} - SD_{HSR})^2} \qquad (8)$$

Where M_{Fi} and M_{HSR} are the means of fused image and HSR image respectively, SD_{Fi} and SD_{HSR} are, respectively, standard deviation of fused image and HSR image.

Higher *CC* or lower spatial *ERGAS* values imply that fusion method has higher spatial quality. In ideal condition, the values of *CC* and spatial *ERGAS* are 1 and zero, respectively. Fusion method has optimal spatial information preservation with HSR image when the values of *CC* are high and the values of spatial *ERGAS* are lower.

3.2 Results on Quickbird Images

A scene of Quickbird images (1600×1600 pixels for HSR image) taken on 21 Nov.2002 were selected as one test data in this paper. The test region of Quickbird covers urban areas of Sundarbans in India. Small areas (308×152 pixels for LRS image) of original HSR and LSR images are shown in Fig. 3.


(a)

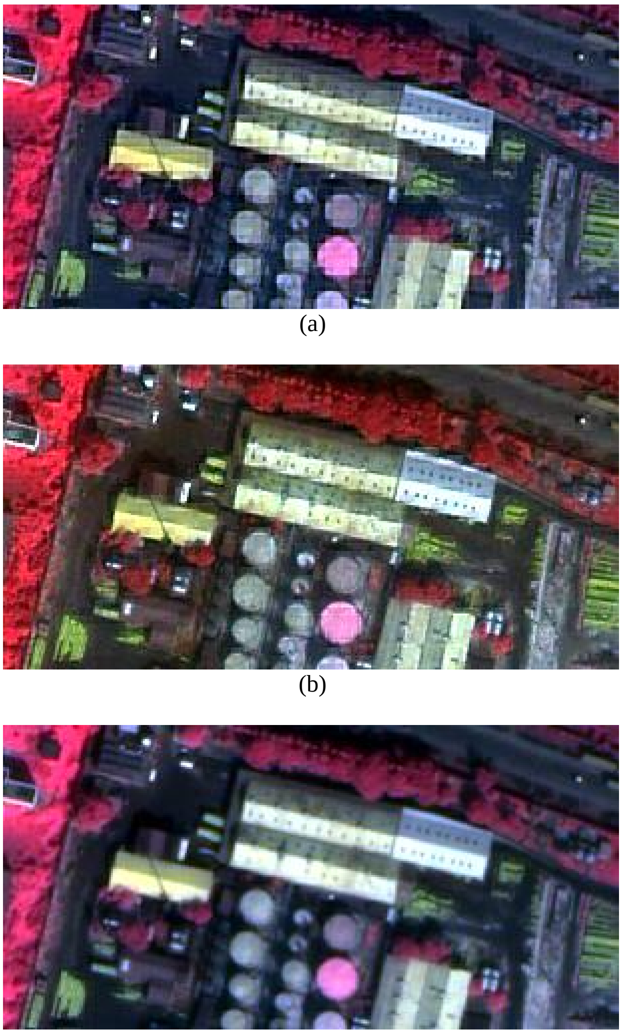
(b)

Figure 3. Original HSR and LSR images of Quickbird. (a) HSR image. (b) RGB false-colour composition 4, 3 and 2 of LSR (resampled at 0.7 m)

RGB compositions of the fused images formed by three fusion methods are shown in Fig. 4. From original images and fusion results (Fig. 3, Fig. 4), the spectral characteristics of SFIM-fused or DWT-fused images is almost the same with original LSR images (Fig. 3(b), Fig. 4(a)-(b)), and that of MBT-fused images has slightly difference (Fig. 3(b), Fig. 4(c)). On the other hand, the improvement of spatial quality is obvious in all fused images. However, there are blurred phenomenon between different objects in both SFIM-fused and WT-fused images (Fig. 4(a)-(b)), and the features in MBT-fused images are the same clear with HSR image (Fig. 4(c), Fig. 3(a)).

Fusion method		Spectral quality		Spatial quality	
		SD	*ERGAS*	*CC*	*ERGAS*
SFIM	MS1	0.003	1.070	0.626	82.535
	MS2	0.003		0.718	
	MS3	0.003		0.711	
	MS4	0.001		0.860	
DWT	MS1	0.008	4.260	0.591	85.518
	MS2	0.009		0.670	
	MS3	0.018		0.645	
	MS4	0.001		0.797	
MBT	MS1	0.016	5.184	0.858	80.757
	MS2	0.015		0.881	
	MS3	0.014		0.823	
	MS4	0.001		0.868	

Table 1. Quantitative evaluation results of Quickbird


(a)

(b)

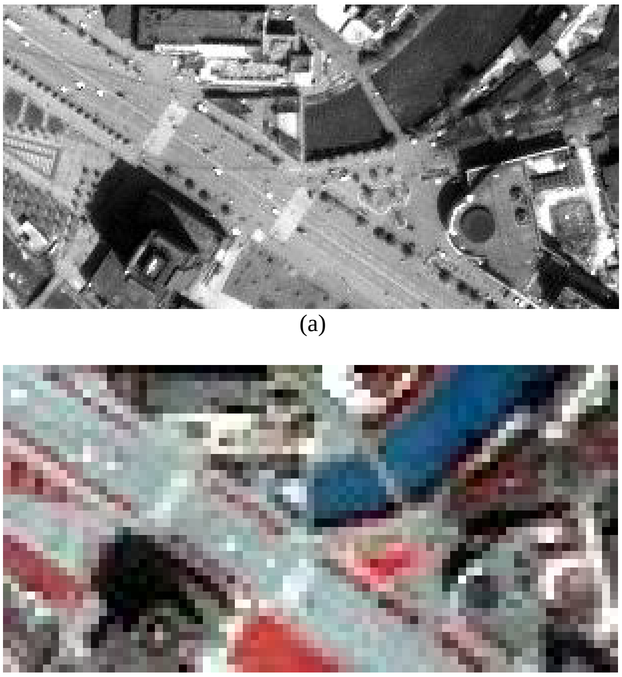
(c)

Figure 4. The fusion results of Quickbird. (a) RGB false-colour composition 4, 3 and 2 of SFIM. (b) RGB false-colour composition 4, 3 and 2 of DWT. (c) RGB false-colour composition 4, 3 and 2 of MBT

Visual evaluation is subjective and nor comprehensive. The evaluation result of fused images with quantitative calculation is a comprehensive evaluation. First, we compare the spectral quality evaluation indexes *SD* and spectral *ERGAS* from Table 1. The index *SD* values of SFIM-fused images are the lowest. The spectral *ERGAS* and average *SD* values of three fusion methods are 1.070 and 0.003 (SFIM), 4.260 and 0.009 (DWT), 5.184 and 0.012 (MBT), respectively. So, both spectral *ERGAS* and average *SD* indexes of SFIM-fused images are more close to zero compared with DWT or MBT. In other words, SFIM fusion method has optimal spectral information preservation with LSR images of Quickbird, followed by DWT and MBT. Then, we analyse the spatial quality evaluation indexes *CC* and spatial *ERGAS*. The value of *CC* index between either band MBT-fused images with HSR image is the highest. The average values of *CC* index of three fusion methods are 0.729 (SFIM), 0.676 (DWT), 0.858 (MBT), and the spatial *ERGAS* indexes of three fusion methods are 82.535 (SFIM), 85.518 (DBT) and 80.757 (MBT), respectively. So, the average *CC* index value of MBT fusion method is the highest among the three fusion methods and the spatial *ERDAS* index value of MBT is the lowest. Thus, MBT fusion method has the highest spatial information preservation with HSR image of Quickbird among three fusion methods used in the paper. The result of quantitative spatial analysis is consistent with the initial visual interpretation (Fig. 3(b), Fig. 4).

3.3 Results on IKONOS Images

A sub-scene of IKONOS image taken on 28 March 2003 is selected as the other kind of test data, which covers an area of the urban area of Dujiangyang city in Sichuan province China. The size of selected HSR image is 1600×1600 pixels (400×400 pixels for LSR images) and Fig.5 is the original HSR image (308×152 pixels) and LSR images.


(a)

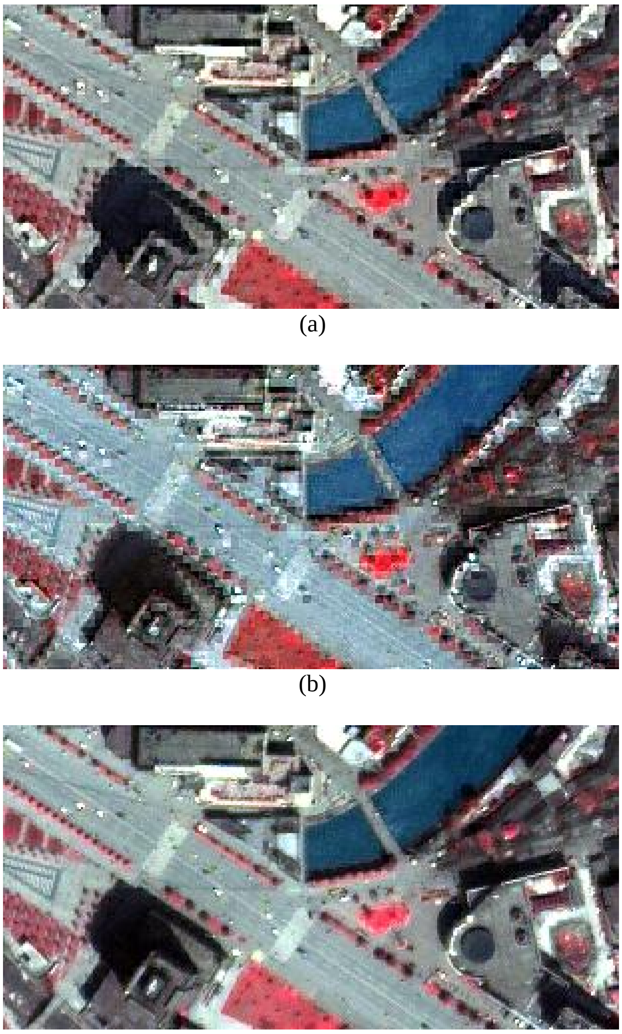
(b)

Figure 5. Original HSR and LSR images of IKONOS. (a) HSR image. (b) RGB false-colour composition 4, 3 and 2 of LSR (resampled at 1 m)

Fusion method		Spectral quality		Spatial quality	
		SD	*ERGAS*	*CC*	*ERGAS*
SFIM	MS1	0.002	0.553	0.894	83.396
	MS2	0.001		0.919	
	MS3	0.001		0.924	
	MS4	0.001		0.910	
DWT	MS1	0.010	6.887	0.712	87.621
	MS2	0.010		0.739	
	MS3	0.018		0.750	
	MS4	0.021		0.707	
MBT	MS1	0.210	85.201	0.958	57.881
	MS2	0.211		0.981	
	MS3	0.213		0.973	
	MS4	0.217		0.922	

Table 2. Quantitative evaluation results of IKONOS

From the fusion results of IKONOS images (Fig. 6), the spectral information of three fusion methods is almost the same with original LSR images (Fig. 6, Fig. 5(b)). On the other hand, the features in fused images are clearer than that in original LSR images. However, the edges between different features are blurred in SFIM-fused images or WT-fused images (Fig. 6(a)-(b)), and the features in MBT-fused images are clearer compared with SFIM-fused or DWT-fused productions (Fig. 6).


(a)

(b)

(c)

Figure 6. The fusion results of IKONOS. (a) RGB false-colour composition 4, 3 and 2 of SFIM. (b) RGB false-colour composition 4, 3 and 2 of DWT. (c) RGB false-colour composition 4, 3 and 2 of MBT

From Table 2, the index *SD* values of SFIM-fused images are the lowest. The spectral *ERGAS* and average *SD* values of three fusion methods are 0.553 and 0.001 (SFIM), 6.887 and 0.015 (DWT), 85.201 and 0.213 (MBT), respectively. So, both average *SD* and spectral *ERGAS* indexes of SFIM-fused images are more close to zero compared with those of DWT or MBT productions. In other words, SFIM fusion method has superior spectral information preservation with LSR images of IKONOS, followed by DWT and MBT. When we come to the spatial quality evaluation indexes *CC* and spatial *ERGAS*. The value of *CC* index between either band MBT-fused images with HSR image is the highest. The average values of *CC* index of three fusion methods are 0.912 (SFIM), 0.727 (DWT), 0.959 (MBT), and the spatial *ERGAS* indexes of three fusion methods are

83.396 (SFIM), 87.621 (DBT) and 57.881 (MBT), respectively. Therefore, the average *CC* index value of MBT fusion method is also the highest among the three fusion methods and the spatial *ERDAS* index value of MBT is also the lowest. So, MBT fusion method also has the highest spatial information preservation with HSR image of IKONOS among three fusion methods.

4. CONCLUSSIONS

In this paper, MBT has been proposed to fuse either individual band LSR images of high resolution remote sensing sensors, such as Quickbird or IKONOS. Three fusion methods, such as SFIM, DWT and MBT, which all can be used to fuse each band LSR images independently, have been employed to fuse four bands LSR (MS) images with HSR (PAN) image of high resolution imageries including Quickbird and IKONOS.

The spectral quality and spatial quality of the fused images based on Quickbird and IKONOS imageries have been evaluated by qualitative visual interpretation and quantitative statistical analysis. The evaluation results confirm that MBT has optimal spatial information preservation with HSR image compared with SFIM and DWT in two fusion results of high spatial resolution images and SFIM has optimal spectral information preservation with LSR images of both Quickbird and IKONOS, respectively.

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