AN IMPROVED IHS FUSION METHOD FOR MERGING MULTI-SPECTRAL AND PANCHROMATIC IMAGES CONSIDERING SENSOR SPECTRAL RESPONSE

Jia Xu, Zequn Guan, Jie Liu

School of Remote Sensing and Information Engineering, Wuhan University, Wuhan, 430079, China
- jiaxu_whu@yahoo.com.cn

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ABSTRACT:

While many remote sensing and GIS applications require both the spatial resolution and spectral resolution be high, image fusion, or in other words, image sharpening, is a useful technique. To date, numerous image fusion techniques have been developed. However, some undesirable effects such as modified spectral signatures and resolution overinjection are produced. In this paper, a novel spectral preservation fusion method for remotely sensed images is presented by considering the physical characteristics of sensors. It is mainly based on the fast intensity-hue-saturation (IHS) transform but improved in two parts: the construction of intensity component and the injection method of detail information. In the proposed method, the spectral sensitivity of the multispectral and panchromatic sensors has been taken into account and all the multispectral bands can be fused at the same time. Experiments carried out on IKONOS, Landsat 7 ETM+ and EO-1 ALI images show that the proposed method can preserve spatial details and minimize spectral distortion.

1. INTRODUCTION

Most of the newest remote sensing systems, such as Landsat 7, SPOT, IKONOS, QuickBird, EO-1, ALOS provide sensors with one high spatial resolution panchromatic (PAN) and several multispectral (MS) bands simultaneously. Meanwhile, an increasing number of applications, such as feature detection, change monitoring, and land cover classification, often demand the use of images with both high spatial and high spectral resolution. As a result, the fusion of HRP and LRM images has become a powerful solution and many image fusion methods have been proposed over the last two decades (Pohl et al,1998; Lau et al, 2000; Wang et al,2005). However, as the physical spectral characteristic of the sensors are not considered during the fusion process, some undesirable effects such as modified spectral signatures and resolution overinjection are produced. Recently, Otazu et al (2005) has presented a technique which takes into account the physical electromagnetic spectrum response of sensors during the fusion process and successfully applied it to wavelet-based image fusion methods7. Some image fusion methods which employ the information of sensor spectral response have already been carried out on IKONOS images and demonstrated to be effective (González-Audicana et al,2006; Dou et al, 2007; Zhang et al,2007).

In this paper, after analyzing and comparing the radiometric properties of different sensors, we present a new improved method based on the fast IHS transform which takes the sensor spectral response into account. The proposed method minimizes spectral distortion and is capable of merging all the MS bands at the same time. To evaluate the performance and efficiency of the proposed method, experiments are carried out on IKONOS, Landsat 7 ETM+ and EO-1 ALI images. The proposed method is compared together with traditional IHS method and three typical modified IHS methods both visually and quantitatively.

2. SPECTRAL CHARACTERISTICS OF SENSORS

Problems and limitations associated with the available fusion techniques have been reported by many studies (Zhang,2000). The most significant problem may be the spectral distortion of fused images. To understand the influence of senor spectral response on panchromatic and multispectral image fusion, the spectral characteristics of different sensors are investigated in detail.

Satellite (Sensor)	Spectral range (μm)	Corresponding MS Bands
Landsat 7	0.52-0.90	2(G)，3(R)，4(NIR)
IKONOS	0.45-0.90	1(B)，2(G)，3(R)，4(NIR)
Quickbird	0.45-0.90	1(B)，2(G)，3(R)，4(NIR)
SPOT 5	0.48-0.71	1(G)，2(R)
IRS P6	0.50-0.85	1(G)，2(R)，3(NIR)
EO1 (ALI)	0.48-0.69	2(B)，3(G)，4(R)
ALOS	0.52-0.77	2(G)，3(R)

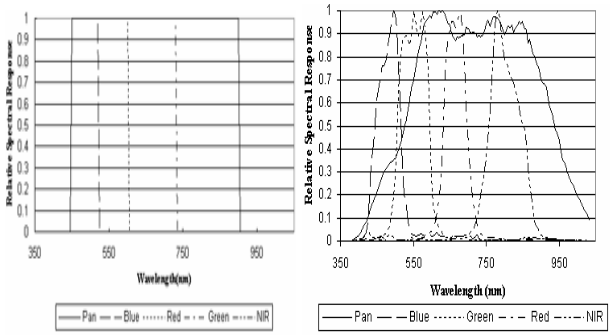
Table1. Spectral ranges of PAN sensors

2.1 Spectral range of panchromatic sensor

A major reason for the significant spectral distortion in image fusion is the wavelength extension of the new satellite PAN sensors. Table 1 shows the spectral ranges of different PAN sensors. It is obvious that their spectral ranges are different. The spectral ranges of IKONOS, QuickBird and Landsat 7 are wider than the others and extended from the visible into the near infrared, which are different from that of SPOT, IRS, ALI and ALOS. This difference makes the grey value relationship of an IKONOS, Quickbird or Landsat 7 panchromatic image significant different from that of other panchromatic images. For example, as the high reflectivity in near infrared band, vegetation areas appear brighter than pavement areas in the IKONOS or Quickbird PAN image, meanwhile in the other PAN images such as SPOT, IRS or ALI, vegetation areas appear darker than pavement areas. As a result, the usual fusion methods are rarely suitable for all data and the good fusion quality depends on the data type and operator's experience.

2.2 Spectral response of Sensors

For most earth resource satellites which provide both PAN and MS bands, in ideal condition, all MS bands would be well separated and would cover exactly the same wavelengths as the PAN band. In addition, the measured energy in the PAN band can be obtained with the summation of corresponding MS bands theoretically. However, there area no sensors show such a situation. Take the sensors onboard of IKONOS for example, the theoretical and actual spectral responses are shown in Figure1.



(a) (b)

Figure1. Relative Spectral response of IKONOS* (a) Theoretical spectral response; (b) Actual spectral response.

In fact, the measured energy in an individual channel is the sum of incoming radiation and relative spectral response:

$$L_k = \int L(\lambda) R_k(\lambda) d\lambda \tag{1}$$

where λ is the wavelength, L_k the in-band radiance, $L(\lambda)$ at-aperture spectral radiance and $R_k(\lambda)$ the peak-normalized spectral response. Therefore, the energy in PAN band of IKONOS can be estimated by defining four weights as follows:

$$Pan = w_B B + w_G G + w_R R + w_{NIR} NIR + (other) \tag{2}$$

where *Pan*, *B*, *G*, *R*, *NIR* represent the radiance of individual spectral bands, w_B, w_G, w_R, w_{NIR} are the weights of corresponding MS bands, and *other* considers for the influence of the spectral range which missing from MS bands but still covered with the PAN band. For other satellites listed in Table 1, the energy in PAN band can be obtained in the same way, and a general equation would be written as:

$$Pan = \sum_i w_i MS_i + (other) \tag{3}$$

where MS_i is the corresponding MS bands which covered with PAN band, and w_i is the weights of band i. It is suitable for most of the satellites which provide both PAN and MS bands.

3. OUTLINE OF PROPOSED METHOD

3.1 Fast IHS image fusion method

In recent years, a variety of image fusion methods have been developed. According to its efficiency and implementation, the IHS image fusion method is probably the most one. To quickly merge massive volumes of data, Tu et al (2004) have proposed a fast approach of IHS fusion to perform the fusion process with lower computational cost. In the fast IHS method, the fused image$[F(R), F(G), F(B)]^T$ can be obtained from the upsampled original image $[R, G, B]^T$ easily by using addition operation, which is expressed as follows:

$$\begin{bmatrix} F(R) \\ F(G) \\ F(B) \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \cdot \begin{bmatrix} I + (I_{new} - I) \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \cdot \begin{bmatrix} I + \delta \\ v1 \\ v2 \end{bmatrix} = \begin{bmatrix} R + \delta \\ G + \delta \\ B + \delta \end{bmatrix} \tag{4}$$

where $\delta = Pan - I$ and $I = (R + G + B)/3$. For IKONOS data fusion, given the spectral range of PAN image, Tu el al solves the spectral distortion problem by including NIR band into *I*, that is $I = (R + G + B + NIR)/4$. To further consider the spectral mismatching between PAN and MS bands, a simple spectral adjustment is presented to use $I_{SA} = (R + 0.75 * G + 0.25 * B + NIR)/3$ to replace *I*.

3.2 Proposed fusion method

According to its fast computing capability for fusing images, the fast IHS fusion method is widely used for fusion purposes and some modified methods have been proposed too (Choi,2006; González-Audicana et al,2006). However, the adjustment and modification are mostly proposed for IKONOS and Quickbird images. Taking the sensor spectral response into account, we present a new improved method based on the fast IHS transform. The improvements are in two parts:

(1) Construction of the intensity component

Considering the relationship between the relative spectral response of MS and PAN sensors which discussed in section 2, the intensity component is generated by combining the MS bands whose spectral ranges are overlapped by the spectral coverage of the PAN band, no matter what combinations of MS bands are being fused. We can define the intensity component (I) as:

*http://www.geoeye.com/products/imagery/ikonos/spectral.htm (accessed 22 Oct. 2006)

$$I = \sum_i w_i MS_i \qquad (5)$$

where MS_i is the corresponding MS bands which covered with PAN band, and w_i is the weights of band i. For IKONOS, MS_i represent blue, green, red and near infrared band. For Landsat7 (ETM+), MS_i represent green, red and near infrared band. And for the other satellites, it can be referred to Table 1.

(2) Modulation of the spatial detail

Similar to GIF method proposed by Wang et al (2005), we introduce a modulation coefficient (α) to modulate the spatial detail. Then the method can extend traditional three-order transformations to an arbitrary order and all the MS bands could be fused at the same time. In this way, the equation (4) would be rewritten as:

$$F(MS_k) = MS_k + a_k \cdot \delta = MS_k + a_k \cdot (I_{new} - I) \qquad (6)$$

where MS_k represent the MS bands which will be fused, I is the intensity component that constructed according to (5), and $a_k = MS_k / I$ in order to keep the added spatial detail proportional to their original values.

Take IKONOS images as an example, the difference among the proposed method, the traditional IHS method, the fast IHS method (FIHS) and the fast IHS method with spectral adjustment (FIHS-SA) are shown in Table 2. In the proposed method, the sensor spectral response has been considered adequately and the spatial detail is injected into each band discriminatively. There are several ways to obtain the weight coefficients (González-Audicana et al,2006; Dou et al,2007). However, they only consider the nominal spectral responses which would be influenced by the on-orbit working conditions, atmospheric effects or postprocessing effects. In this paper, the PAN image is degraded to the same resolution as MS images by means of low-pass filtering and subsampling. Assumed that degraded PAN and MS bands satisfy the equation (3), a linear regression algorithm is performed in order to estimate the weight coefficients. Considering that there is a constant item (*other*) in equation (3), an adjustment of mean value is required to keep the global spectral balance.

Fusion method	w_1	w_2	w_3	w_4	a_k
IHS	1/3	1/3	1/3	0	1
FIHS	1/4	1/4	1/4	1/4	1
FIHS-SA	1/12	1/4	1/3	1/3	1
Proposed method	w_B	w_G	w_R	w_{NIR}	MS_k/I

Table2. Comparisons of different fusion methods

4. EXPERIMENTAL RESULTS

To evaluate the performance and efficiency of the proposed method, experiments are carried out on IKONOS, Landsat 7 ETM+ and EO-1 ALI images respectively. For the experiment on the fusion of IKONOS images, the original PAN and MS images are first atmospherically corrected and then spatially degraded to a resolution of 4 and 16 meter, respectively. The performance of the proposed method is compared together with traditional IHS method and three typical modified IHS methods (IIHS method proposed by Xiao 2003; FIHS method proposed by Tu,2004; IHS-WT method provided in ERDAS) both visually and quantitatively. Part of image is extracted to compare the visual effect of the fused images with reference image (the original MS image). From Figure.2, it can be easily seen that the fused image generated from traditional IHS method has obvious colour distortion. The spectral quality of FIHS fusion result has improved to some extent, but the colour of vegetation area in top right corner is still changed. The fused images generated from IIHS and IHS-WT methods keep good spectral quality, but the spatial quality of them are not as good as the other ones. The proposed method preserves almost all the spatial details and minimizes spectral distortion. The fused image generated from it is most similar to the reference image.

To quantitatively assess the spectral and spatial quality of the fused images, some indices including bias, correlation coefficient (CC), spatial correlation coefficient (sCC,), and the universal image quality index (UIQI) are used. The bias refers to the difference between the means of the fused and reference images. The smaller the difference, the better the spectral quality is. The CC between the fused and reference image shows similarity between them. The sCC is proposed by Zhou et al (1998). In the procedure, the PAN and fused images are filtered with a Laplacian filter and the correlation coefficient between the filtered images is defined as sCC. The high correlation coefficients indicate that most of the spatial details are injected during the merging process. The UIQI indicates the spectral quality of the fused image (Wang et al,2002). The bigger the value of UIQI, the better the spectral quality is. From Table 2, we can find that except a litter smaller in CC index than IHS-WT method, the proposed method has superior performance than other methods in both the bias and UIQI index, which means the smallest spectral distortion. Furthermore, it is clear that the fused image from the proposed method has a similar sCC in comparison to those generated from IHS and FIHS method, which is much higher than those from IIHS and IHS-WT methods. To sum up, the proposed method has the best comprehensive performance.

In addition, the experiment results of Landsat 7 ETM+ and EO-1 ALI images are shown in Figure 3 and Figure 4 respectively. For better comparison, a subset of images and the fused results are selected and displayed by using the same linear stretch method. From the picture, it is noticeable that the fused images from the traditional IHS method have obvious spectral distortion, such as the airport runway and water in Figure 3 and the vegetation area in Figure 4. Unlike the traditional IHS method, the improved IHS fusion method proposed in this paper generates fused images with both high spectral fidelity and high spatial resolution. Moreover, all the MS bands (IKONOS (1-4), ETM+ (1-5, 7)) have been fused at the same time by using the proposed method.

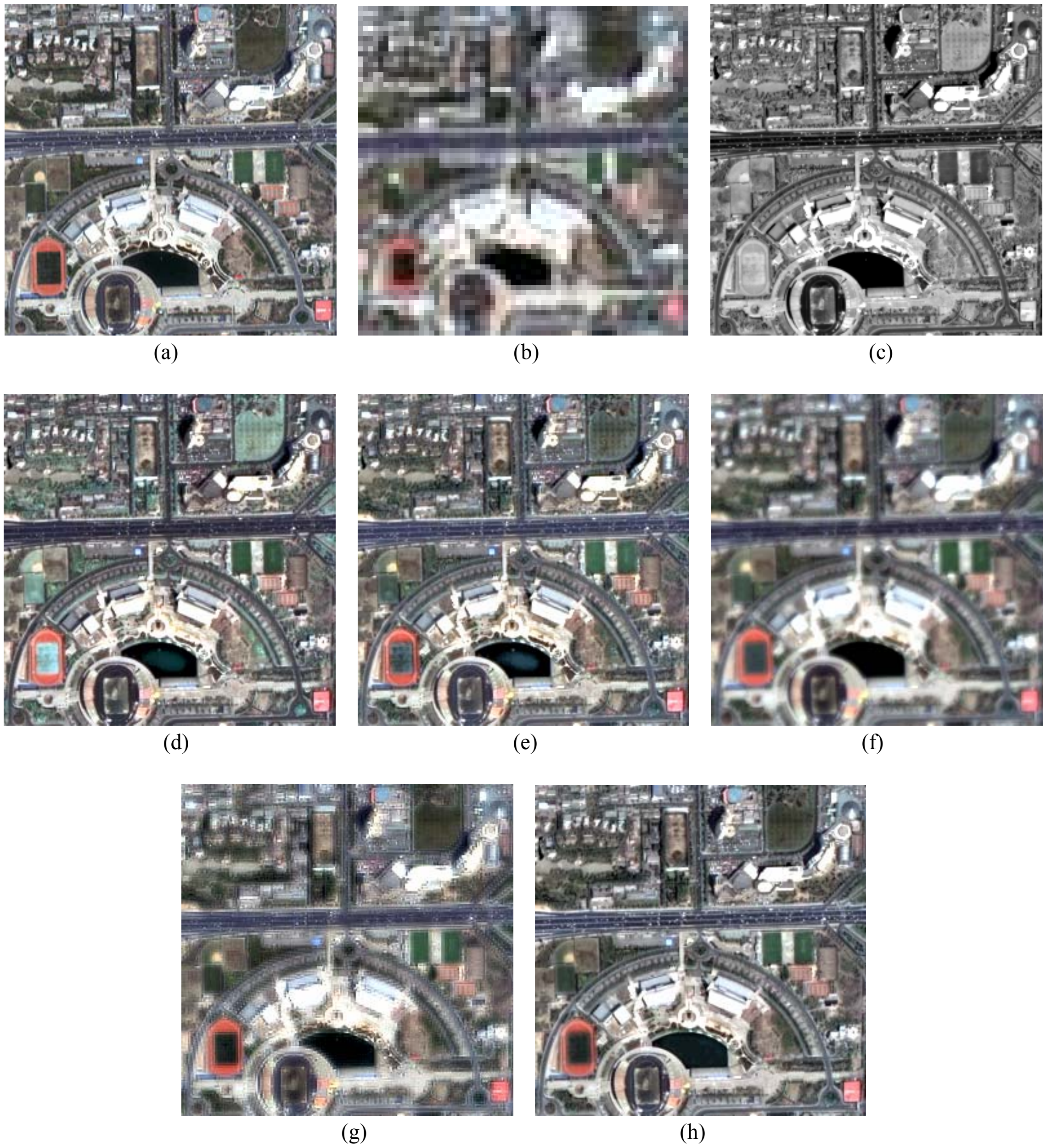


Figure2. Part of IKONOS MS, PAN images and fusion results: RGB (321) combination. (a) Original MS image (4m); (b) Degraded MS image (16m); (c) Degraded PAN image (4m); (d)Fused by HIS; (e) Fused by FIHS; (f) Fused by IIHS; (g) Fused by IHS-WT; (h) Fused by Proposed method.

Index	Band	IHS	FIHS	IIHS	IHS-WT	Proposed method
bias	B	1.0240	0.8411	0.9169	0.5093	0.4856
	G	0.9307	0.8223	0.8656	0.5016	0.4660
	R	1.0271	0.8168	0.8912	0.5309	0.4818
	NIR	—	0.8808	-	-	0.5120
CC	B	0.6567	0.7749	0.8693	0.8719	0.8632
	G	0.7021	0.8200	0.8882	0.8802	0.8733
	R	0.7843	0.8561	0.9038	0.8958	0.8976
	NIR	-	0.8607	-	-	0.8723
sCC	B	0.9927	0.9916	0.9605	0.6297	0.9818
	G	0.9942	0.9921	0.9571	0.6311	0.9887
	R	0.9897	0.9836	0.9471	0.6326	0.9840

	NIR	-	0.9854	-	-	0.9843
UIQI	B	0.6396	0.7443	0.8333	0.8530	0.8620
	G	0.6870	0.7856	0.8556	0.8586	0.8710
	R	0.7607	0.8186	0.8713	0.8712	0.8910
	NIR	-	0.8535	-	-	0.8676

Table3. Quantitative analysis of different fusion methods

5. CONCLUSION

In ideal condition, a good image fusion method tries to generate the image which a sensor would obtain if it had the same spectral response of the original MS sensor but the spatial resolution of the PAN sensor. As a result, to preserve spatial details and minimize spectral distortion, the spectral characteristics of sensors have to be taken into account. The proposed method is based on the generalized fast IHS fusion framework and two improvements are proposed by considering sensor spectral response. As shown from the different fusion experiments, the proposed method has a superior comprehensive performance and performs better than other IHS fusion methods regarding both spectral and spatial quality. It is suitable for various satellite images and extends traditional three-order transformations to an arbitrary order.

(a) (b) (c)

Figure3. Part of Landsat7 ETM+ MS image and fusion result: RGB (743) combination. (a) Original MS image; (b) Fused by IHS method; (c) Fused by proposed method

(a) (b) (c)

Figure4. Part of EO-1 ALI MS image and fusion result: RGB (432) combination. (a) Original MS image; (b) Fused by IHS method; (c) Fused by proposed method

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