AN IMPROVED IHS IMAGE FUSION METHOD WITH HIGH SPECTRAL FIDELITY

Wen Dou[a], Yunhao Chen[b]

[a] Department of Geographic Information Engineering, Southeast University, Nanjing, Jiangsu, 210096 P. R. China - douw@seu.edu.cn
[b] College of Resource Science, Beijing Normal University, Beijing, 100875 P. R. China - cyh@ires.cn

Commission WG VII/6

KEY WORDS: remote sensing, image fusion, histogram match, IHS

ABSTRACT:

Image fusion is a critical issue for remote sensing, and many algorithms have been developed. Image quality assessment of fused image might provide comparison between fusion methods, but the conclusion is not so general because different test images would lead to different assessment results. The paper studies on the relationships between image fusion methods aiming to reveal the nature of various methods. By doing so, we could compare the performance of spatial enhancement and spectral fidelity from mathematical form of image fusion processes.

1. INTRODUCTION

Methods based on the Intensity Hue Saturation (IHS) transform are probably the most popular approaches used for enhancing the spatial resolution of multispectral (MS) images with panchromatic (PAN) images (Tu, T.M., *et al.*,2004). The IHS method is capable of quickly merging the massive volumes of data by requiring only resampled MS data. Particularly for those users, not familiar with spatial filtering, IHS can profitably offer a satisfactory fused product.

The main concept of the IHS method is based on the representation of low-resolution MS images in the IHS system and then substituting the Intensity component I with the PAN image. However, IHS and other so-called "component substitution" methods would introduce spectral distortion into the resulting MS images, appearing as a change in colors between compositions of resampled and fused multispectral bands. Such methods take redundant information of the PAN and MS imagery as the basis of image fusion, and hypothesize that PAN image and the Intensity component of the MS image, which is retrieved based on the RGB color model, contain almost the same information. That means PAN is taken as the high resolution intensity component of the high resolution multispectral data. Based on such hypothesis, spatial detail is the difference of PAN and the low resolution I component, and is injected into the MS image by substituting the I component with the PAN image.

Unfortunately, it is impossible to construct I component containing same information as PAN image. That means spatial detail could be far from the truth when I component is constructed in an improper way. Therefore, introduction of spectral distortion is partly due to the construction of spatial detail.

2. ANALYSIS ON HISTOGRAM MATCHING PROCESS

For the IHS method, *I* component is constructed by the average of R,G,B band. Before *I* is substituted with PAN image, histogram matching should be implemented to make the PAN image has the same average and standard deviation with the low resolution I component as (1).

$$I^h = (PAN - \mu_{PAN})\frac{\sigma_I}{\sigma_{PAN}} + \mu_I \tag{1}$$

where I^h is high resolution intensity component, μ_{PAN} and μ_I are average of *PAN* and *I* respectively, and σ_{PAN} and σ_I are standard deviation of *PAN* and *I* respectively.

It seems that the process is reasonable to make *I* and *PAN* comparable. However, an image vector space V is introduced to analyze histogram matching process, in which a single band image could be represented as a vector. For any vector ξ and η in V, dot product is defined as

$$<\xi,\eta> = cov(\xi,\eta) \tag{2}$$

where $cov(\xi,\eta)$ is covariation of ξ and η.

It is easy to prove that the vector space V with this operation is an inner product space. Module of vector and angle of two vectors α is

$$|\xi| = \sqrt{<\xi,\xi>} = \sigma(\xi) \tag{3}$$

$$\begin{aligned}\cos\alpha &= \frac{<\xi,\eta>}{\sqrt{<\xi,\xi>\cdot<\eta,\eta>}} \\ &= \frac{\sigma(\xi,\eta)}{\sigma(\xi)\cdot\sigma(\eta)} \\ &= \rho(\xi,\eta)\end{aligned} \quad (4)$$

where ρ is correlation coefficient.

Fig.1 illustrates the process of traditional histogram matching. Let vector $\overrightarrow{OP}$ be the PAN image, vector $\overrightarrow{OS}$ be the low resolution I component, then $\overrightarrow{OP'}$ is the image retrieved from PAN following (1), where $|\overrightarrow{OP'}| = |\overrightarrow{OS}|$, and $\overrightarrow{SP'}$ is the spatial detail provided by PAN image.

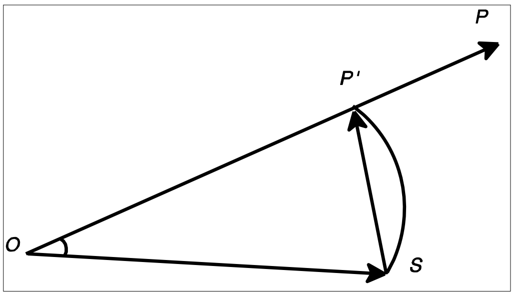


Figure 1: Traditional Histogram Matching Process

From Fig.1 it is easy to find out that the angle between $\overrightarrow{OS}$ and $\overrightarrow{SP'}$ is greater than $\frac{\pi}{2}$. From (4) it is known that spatial detail retrieved by this way must have negative correlation with I component. In other words, more detail would be injected to the part with low intensity, and less detail would be injected to the part with high intensity. Such result is not so reasonable, which might lead to spectral distortion and suppression of spatial detail. Moreover, weak correlation between PAN and I, which means a bigger $\angle POS$, would aggravate the problem.

Hence, the paper proposes a new histogram matching method to avoid the problem and improve IHS method in spectral fidelity. To avoid the problem raised above, it is intuitive to take $\overrightarrow{SP'} \perp \overrightarrow{OS}$ as the constraint to the histogram matching process. Fig.2 illustrates the process. By this way, spatial detail extracted must be orthogonal to I component, and has a positive correlation with PAN image. Moreover, $|\overrightarrow{SP'}|$ is larger in Fig.2 than in Fig.1, which means stronger spatial detail and would lead to sharper fusion result.

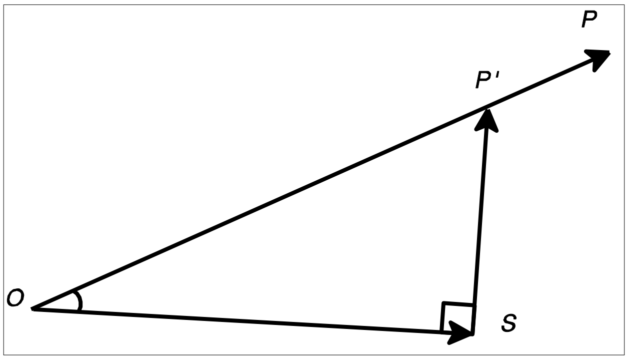


Figure 2: Improved Histogram Matching Process

Based on Fig.2, the improved histogram matching process is

$$I^{b} = (PAN - \mu_{PAN})\frac{\sigma_I}{\sigma_{PAN}\rho_{I,PAN}} + \mu_I \quad (5)$$

where $\rho_{I,PAN}$ is correlation coefficient between I and PAN image.

3. DATA AND RESULTS

The method was tested for IKONOS II image of Beijing, China, dated of 06/28/2002. Spatial resolution is 4m for MS and 1m for PAN. To validate the fusion result, MS and PAN image are degraded to 16m and 4m respectively, and image fusion is implemented on the degraded image to take the original MS image as (Wald, L.,1999). IHS cylinder model (Zhou, J., *et al.*,1998) is employed, transform and inverse transform is shown in (6) and (7).

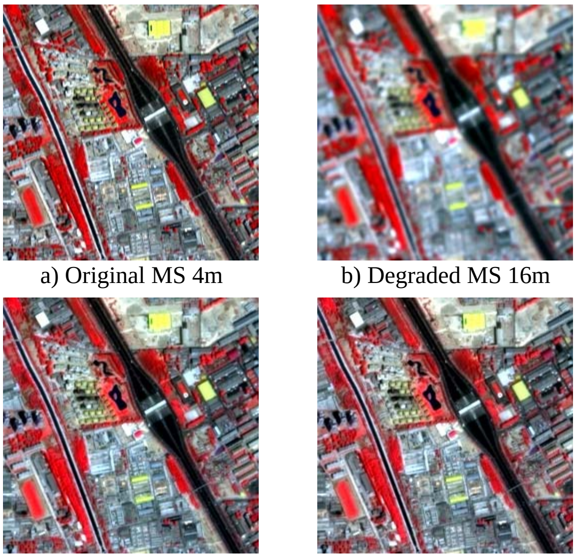
$$\begin{bmatrix} I \\ v_1 \\ v_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & \frac{-2}{\sqrt{6}} \\ \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} & 0 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (6)$$

$$H = \arctan(\frac{v_2}{v_1}), \qquad S = \sqrt{v_1^2 + v_2^2}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{6}} & \frac{-1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{-2}{\sqrt{6}} & 0 \end{bmatrix} \cdot \begin{bmatrix} I \\ v_1 \\ v_2 \end{bmatrix} \quad (7)$$

$$v_1 = S \cdot \cos(H), \qquad v_2 = S \cdot \sin(H)$$

To validate the influence of (5) on IHS method, traditional IHS method using (1) is also applied on the degraded data to compare with the proposed method. Test data and fusion result is shown in Fig.III.



a) Original MS 4m　b) Degraded MS 16m

c) Traditional IHS Result　d) Improved IHS Result

Figure 3: Image Fusion Result

VALIDATION AND DISCUSSION

3.1 Visual Comparison

Comparing Fig.3(d) and Fig.3(c) with Fig.3(a), it is found that result retrieved from traditional method is a little too blue and grey, while the proposed method is closer to the reference image in tone.

3.2 Quantitative Assessment

Three image indexes is used to assess the fusion result compared to original MS image. Average gradient (AG) assess sharpness of image, which is calculated by (8) and the assessment is shown in Table 1.

$$\bar{G} = \frac{1}{(M-1)(N-1)} \sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{\frac{\left(\frac{\partial Z(x_i,y_j)}{\partial x_i}\right) + \left(\frac{\partial Z(x_i,y_j)}{\partial y_j}\right)}{2}} \qquad (8)$$

where $\boldsymbol{M}$, $\boldsymbol{N}$ is column and row number of the image $\boldsymbol{Z}$.

Relative difference (RD) is an index to assess the distortion of fused image compared with reference image. RD is calculated by (9) and the result is shown in Table 2.

$$D = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{|F(x_i,y_j) - A(x_i,y_j)|}{A(x_i,y_j)} \qquad (9)$$

where $\boldsymbol{A}$ and $\boldsymbol{F}$ are reference image and fused image respectively.

UIQI is a comprehensive image quality index (Wang, Z., *et al.*,2002), which has been used to measure the similarity between two images. UIQI is defined as (10) and the result is shown in Table 3.

$$Q = \frac{\sigma_{AB}}{\sigma_A \sigma_B} \cdot \frac{2\mu_A \mu_B}{\mu_A^2 + \mu_B^2} \cdot \frac{2\sigma_A \sigma_B}{\sigma_A^2 + \sigma_B^2} \qquad (10)$$

Band	**Origin**	**IHS**	**Proposed Method**
1	10.1021	13.1679	14.9425
2	17.6524	14.5899	16.3799
3	23.0011	15.8605	17.6275
4	30.8366	17.1412	18.8309

Table 1: Average Gradient of Reference and the Two Fused Images

Band	**IHS**	**Proposed Method**
1	0.024133	0.024763
2	0.0256	0.024226
3	0.03775	0.034866
4	0.042655	0.039324

Table 2: Relative Difference between Reference and the Two Fused Images

Band	**IHS**	**Proposed Method**
1	0.827015	0.84231
2	0.92246	0.93537
3	0.936051	0.947459
4	0.91383	0.926604

Table 3: UIQI between Reference and the Two Fused Images

Table 1 shows that the fusion result retrieved from the proposed method is sharper than traditional method in every band and is closer to the reference image except band 1. Such result is expected because the improved histogram matching method extract more spatial detail. Table 2 shows that the proposed method lead to less RD than traditional method in every band, which means less spectral distortion is introduced by employing the improved histogram matching method. Table 3 shows that the proposed method produces fusion image with higher UIQI than traditional IHS method, which is caused by higher sharpness and lower spectral distortion.

4. CONCLUSION

The paper proposed an improved IHS image fusion method by proposing a new histogram matching method. Histogram matching process is analyzed and improved by introducing an image vector space. The fusion result of the proposed method is satisfactory. As histogram matching is a necessary step for most image fusion methods, the proposed histogram matching method could be applied to improve those methods.

ACKNOWLEDGMENT

The author would like to thank Prof. Li Jing of Beijing Normal University. This study was funded by the Natural Science Foundation of China (40671122).

REFERENCE

Tu, T.M., *et al*.,2004. A fast intensity-hue-saturation fusion technique with spectral adjustment for IKONOS imagery. *Geoscience and Remote Sensing Letters, IEEE*, 1(4), pp. 309-312.

Wald, L.,1999. Some terms of reference in data fusion. *Geoscience and Remote Sensing, IEEE Transactions on*, 37(3), pp. 1190-1193.

Zhou, J., *et al.*,1998. A wavelet transform method to merge landsat TM and SPOT panchromatic data. *International Journal of Remote Sensing*, 19(4) pp. 743-757

Wang, Z., *et al.*,2002. A universal image quality index. *IEEE Signal Processing Letters*, 9(3), pp. 81-84.