

A Spatially Correlated Image Fusion Algorithm for Multispectral Remotely Sensed Imagery

Chen Shao-Ang¹, Hsuan Ren²

¹Department of Graduate Institute of Space Science, National Central University, Taiwan

²Center for Space and Remote Sensing Research, National Central University, Taiwan

E-mail: ¹c2707637@gmail.com, ²hren@csrsr.ncu.edu.tw

KEY WORDS: Intensity-Hue-Saturation (IHS), fusion, multispectral, tradeoff parameter.

ABSTRACT: Image fusion is a very useful method to combine the spectral information from multispectral images with the high spatial resolution panchromatic images to improve the spatial resolution of multispectral images. The fast Intensity-Hue-Saturation (IHS) fusion technique proposed by Tu is based on color systems transformation between RGB and IHS color spaces [2]. In 2006, Choi improved this method by introducing a tradeoff parameter which can control spatial resolution of fusion result [1]. But Choi's method only uses single parameter for all pixels. In this study, we use the correlation of each pixel in multispectral image to create a transform, and assign tradeoff parameter for each pixel by a linear transform to reach minimum mean squared error between the fused image and the origin one.

1. INTRODUCTION

Multispectral sensors on the satellites collect radiance information from the ground with several frequency bands to form a co-registered image cube. It provides useful information for spectral analysis, but it usually has low spatial resolution larger than ten meters. On the other hand, remote sensing satellites also collect panchromatic images with wide bandwidth but higher spatial resolution less than one meter. How to combine the spectral information from multispectral images with the high spatial resolution panchromatic images has been researched intensively.

Many researches have been published in the past few years. The Intensity-Hue-Saturation (IHS) fusion technique base on color systems transformation between RGB and IHS color spaces shows promising results [3,4]. It views multispectral image as RGB and converts them into IHS space, and then substitutes the intensity image with panchromatic ones. After transforming back to RGB from IHS space, the high spatial resolution multispectral image is achieved. The fast IHS fusion proposed by Tu improves the original IHS method by reducing its computational complexity and speed up the algorithm. In 2006, Choi improves this method by introducing a tradeoff parameter. With this parameter, it produces high resolution intensity image by linearly mixed the intensity feature from multispectral image and the panchromatic one. The ratio of mixture is also controlled by this parameter. An appropriate choice of the tradeoff parameter can provide better fusion result both visually and quantitatively. But Choi's method uses a single

tradeoff parameter for all pixels in the image. In this study, we calculate the correlation of each pixel in multispectral image to create a transform, and assign tradeoff parameter for each pixel by a linear transform to reach minimum mean squared error between the fused image and the origin one.

2. A NEW PROPOSE IMAGE FUSION METHOD

In this section, two Intensity-Hue-Saturation fusion methods are reviewed, and based on these methods, a new improved version is proposed.

2.1 Fast Intensity-Hue-Saturation Fusion Method

IHS fusion method is widely used in image fusion techniques. It transfer image from RGB color space to IHS color space in Eq. (1), and replace intensity feature by high spatial resolution panchromatic image. Then transfer image from IHS space back to RGB space in Eq. (2). Fast IHS fusion method is based on IHS fusion method, but it is more convenient and faster, as shown in Eq. (3). Where $I_{New}=Pan$.

$$\begin{bmatrix} I \\ vI \\ v2 \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \dots (1), \quad \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I \\ vI \\ v2 \end{bmatrix} \dots (2)$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} I + I_{New} - I \\ vI \\ v2 \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} I_{New} - I \\ I_{New} - I \\ I_{New} - I \end{bmatrix} \dots (3)$$

2.2 Image Fusion With a Tradeoff Parameter

IHS fusion theory is replacing multispectral image's intensity by panchromatic image. But actually multispectral sensor's wavelength is not equal to panchromatic sensor's, hence Choi proposed the method in 2006. He assumes the high spatial resolution intensity can produced by linearly mixed the intensity feature of multispectral image and the panchromatic image. He introduces a tradeoff parameter t to control the ratio of mixture.

$$\begin{bmatrix} R_{New} \\ G_{New} \\ B_{New} \end{bmatrix} = \begin{bmatrix} R + I_{New} - I \\ G + I_{New} - I \\ B + I_{New} - I \end{bmatrix} = \begin{bmatrix} R + (Pan - (Pan - I)/t) - I \\ G + (Pan - (Pan - I)/t) - I \\ B + (Pan - (Pan - I)/t) - I \end{bmatrix} \dots (4)$$

If we let $t=1$ ($I_{New}=I$), the fused image is equal to the original multispectral image. If $t=2$, then $I_{New}=(Pan+I)/2$, and if we set $t=\infty$, $I_{New}=Pan$, the fused result will be the fast IHS fusion result. Hence, the ratio of panchromatic image in fused one is increase when t increases, and the portion of multispectral image decreases. Which resulting the increases in spatial resolution, but the decreases in spectral one. Therefore, it is crucial to find an adaptable parameter t , so that the fused image will have both good spatial and spectral resolution.

This method also can expend to N bands image fusion by Eq. (5).

$$\begin{bmatrix} Band1_{New} \\ Band2_{New} \\ \vdots \\ BandN_{New} \end{bmatrix} = \begin{bmatrix} Band1 + (Pan - (Pan - I)/t) - I \\ Band2 + (Pan - (Pan - I)/t) - I \\ \vdots \\ BandN + (Pan - (Pan - I)/t) - I \end{bmatrix} \dots (5)$$

Where $I=(Band1+Band2+\dots+BandN)/N$.

2.3 New Image Fusion Algorithm

Choi's algorithm uses single t parameter for all pixels in the image, which means the ratio of mixture is the same for all pixels. But this assumption may not be appropriate; each pixel may have its own adaptable parameter. Therefore, we propose to design a tradeoff parameter for each pixel with the minimum mean squared error (MSE) between original image and fused image.

Assume the original multispectral image is $M_0 = [R_0 \ G_0 \ B_0]^T$, the low spatial resolution multispectral image is $M' = [R' \ G' \ B']^T$, and the fused image is $M_f = [R_f \ G_f \ B_f]^T$. Let n be the difference between original multispectral image and fused one.

$$n = \begin{bmatrix} R_f \\ G_f \\ B_f \end{bmatrix} - \begin{bmatrix} R_0 \\ G_0 \\ B_0 \end{bmatrix} = \begin{bmatrix} Pan - (Pan - I')/t - I' \\ Pan - (Pan - I')/t - I' \\ Pan - (Pan - I')/t - I' \end{bmatrix} + \begin{bmatrix} R' - R_0 \\ G' - G_0 \\ B' - B_0 \end{bmatrix}$$

$$I' = (R' + G' + B')/3$$

The sum of squared error is defined by $E = n^T n$, and the $MSE = \frac{E}{\text{band number}}$.

Assume $\frac{dE}{dt} = 0$, E will be maximum or minimum.

When $\frac{dE}{dt} = 0$, $Pan - I' \neq 0$, $t \neq 0$ and $I_0 = (R_0 + G_0 + B_0)/3$, and then $t = \frac{Pan - I'}{Pan - I_0}$.

The equation will be $\begin{bmatrix} R_f \\ G_f \\ B_f \end{bmatrix} = \begin{bmatrix} R' - I_0 - I' \\ G' - I_0 - I' \\ B' - I_0 - I' \end{bmatrix}$, which means $I_{New} = I_0$.

So when $t = (Pan - I')/(Pan - I_0)$, E and MSE will be minimum. To calculate the t parameter for all pixels in image, it can result a matrix t for fusion. But in practical, we don't have the original image intensity (I_0) to calculate the true t , so we need to reduce the spatial resolution of the multispectral image and panchromatic one, and use these data to estimate the parameter matrix t by artificial an linear transform $W = [w_1 \ w_2 \ w_3 \ w_4 \ c]^T$.

Assume $A * W = t$, where $A = [R' \ G' \ B' \ Pan \ 1]$, $R' = [R'_1 \ R'_2 \ \dots \ R'_N]^T$, $G' = [G'_1 \ G'_2 \ \dots \ G'_N]^T$, $B' = [B'_1 \ B'_2 \ \dots \ B'_N]^T$, $Pan = [Pan_1 \ Pan_2 \ \dots \ Pan_N]^T$, and N is number of pixel. We can calculate the W by least square solution [5], and then we input the original multispectral image and original panchromatic image, and the output, estimated parameter t , will be used for fusion.

3. Experiment and Analysis

A SPOT-5 image scene is used for experiments, and the image location is on Taichung, Taiwan. The multispectral image has 10-m spatial resolution and 4 bands, green (G), red (R), near-infrared (NIR) and short wave infrared (SWIR). The panchromatic image has 2.5-m spatial resolution. The image size of the original multispectral and panchromatic image scene is 1024*1024 and 4096*4096 pixels respectively. The procedure is listed in Fig. 1 and followings.

1. Reduce the image size of original multispectral and panchromatic image to 256*256 (M) and 1024*1024 (Pan) respectively. The multispectral image has four bands: G , R , NIR and $SWIR$.
2. For calculate the transform W , we further reduce M and Pan image to 64*64 (M') and 256*256 (Pan') respectively. Where M' has four bands: G' , R' , NIR' and $SWIR'$.

3. Calculate t' matrix, $t'_n = \frac{Pan'_n - I'_n}{Pan'_n - I_n}$, n is number of pixel.

Where $I' = (G' + R' + NIR' + SWIR')/4$ and $I = (G + R + NIR + SWIR)/4$.

4. Set $A*W = t'$, where $A = [G' \ R' \ NIR' \ SWIR' \ Pan' \ I]$, $G' = [G'_1 \ G'_2 \ \dots \ G'_n]^T$, $R' = [R'_1 \ R'_2 \ \dots \ R'_n]^T$, $NIR' = [NIR'_1 \ NIR'_2 \ \dots \ NIR'_n]^T$,

$SWIR' = [SWIR'_1 \ SWIR'_2 \ \dots \ SWIR'_n]^T$ and $Pan' = [Pan'_1 \ Pan'_2 \ \dots \ Pan'_n]^T$.

5. t matrix can calculate by $t = [G \ R \ NIR \ SWIR \ Pan \ I]^T * W$, and then the fusion result can be calculated by Eq. (6).

$$M_f = M + \left(Pan - \frac{Pan - I}{t} - I \right) \dots (6)$$

The original multispectral image, fused image, IHS fusion result and choi's fusion method result is displayed in Fig. 3. To compare the visual difference of fusion results, Fig. 3 (c) and (e) are similar to the original image, while (d) is the most different one. By Choi's method, when t increases, the fused image becomes darker than the original one. It is because the I_{New} mixes with more portion of the panchromatic image. Fig.2 shows the difference between I (Fig.2 a) and Pan (Fig.2 b), and it is clear that the Pan is darker than I . Therefore, if the IHS method is applied with large t parameter, the fused result will show visual difference.

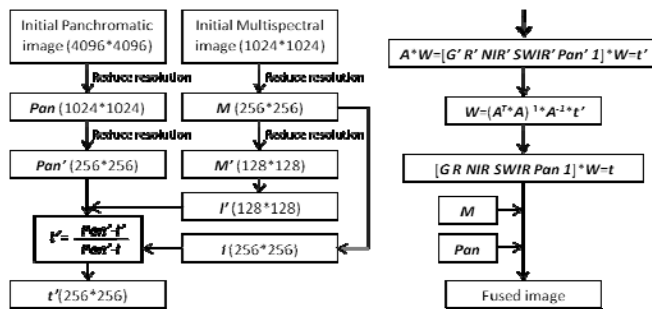
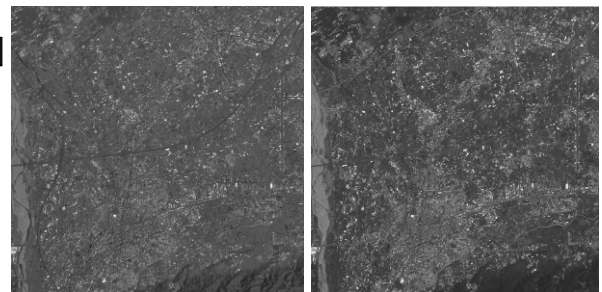
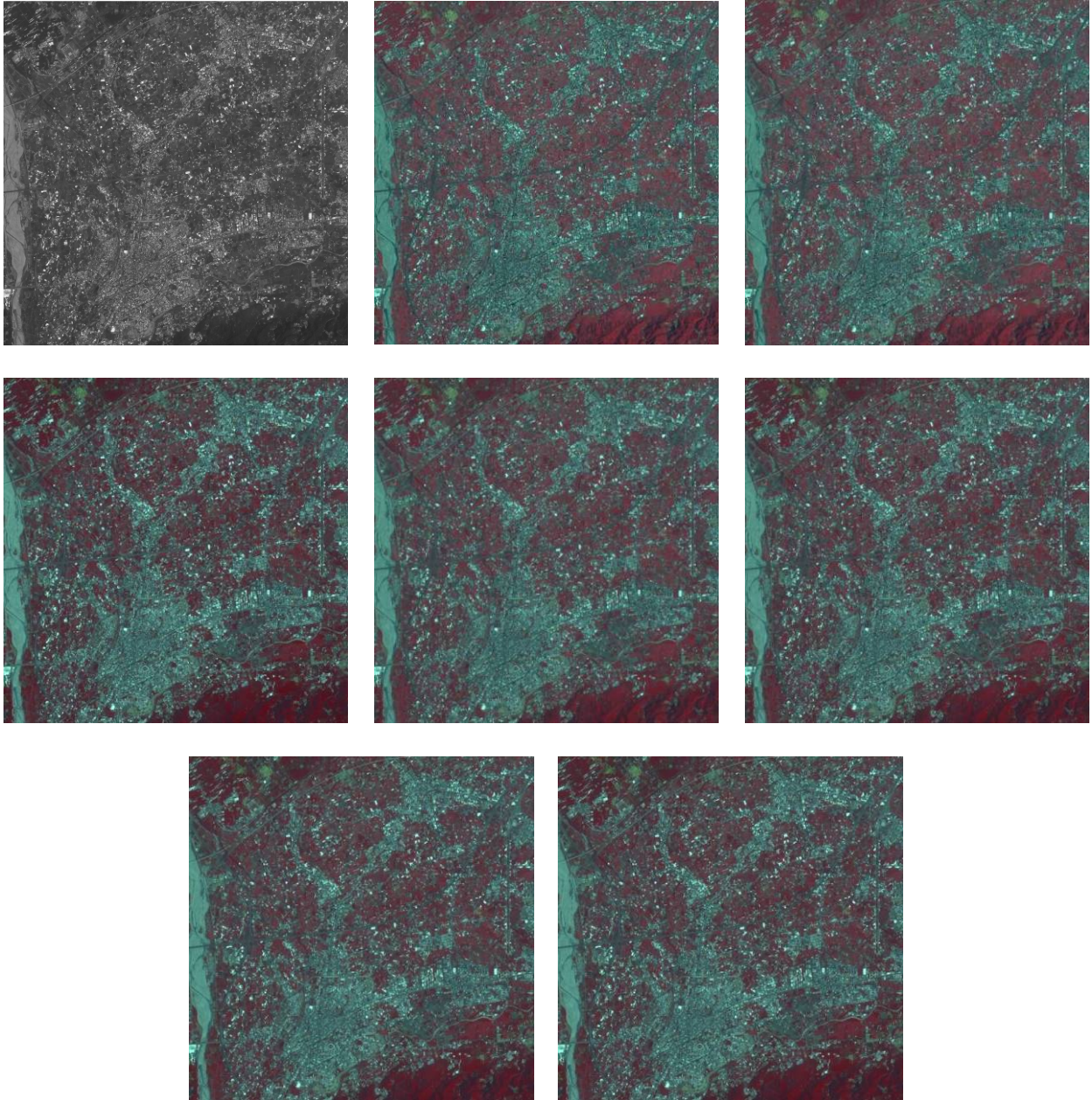


Fig.1 The procedure of fusion



(a) Intensity of multispectral image,
(b) Panchromatic image



(a)	(b)	(c)
(d)	(e)	(f)
(g)	(h)	

Fig.3 SPOT-5 image of Taiwan, R: NIR band, G: Red band, B: Green Band. (a) Original panchromatic image. (b) Original multispectral image. (c) Result image for t matrix. (d) Fused by IHS method. (e) Result image for $t=2$. (f) Result image for $t=3$. (g) Result image for $t=4$. (h) Result image for $t=5$.

The quality analysis result is shown in Table 1. Four indexes are computed, including MSE, Peak Signal to Noise Ratio (PSNR), Correlation Coefficient (CC) and Bias. We conduct comparison with new fusion method, IHS method and $t=2$ to $t=5$ of Choi's method. Compare the value of MSE index, proposed method gives slightly smaller value than Choi's $t=2$, and much lower than all others. The PSNR index and CC index are both show similar results, the proposed method also gives the largest value among all methods, and particularly the lowest bias. Based on Fig. 3 and Table 1, our proposed method shows good visual quality and lowest error to the original images.

4. Conclusion

Our proposed method creates a linear transform function for fusion of multispectral and panchromatic images. It improves Choi's IHS method by training the tradeoff parameter for each pixel instead of using a fix one for the whole image. The experimental results with a SPOT-5 image scene shows similar fusion result to the original image by visual inspection. The image quality is also compared with four indexes: MSE, PSNR, CC and Bias. The proposed method not only shows good image quality but also well by visual inspection.

5. References

1. Myungjin Choi, "A New Intensity-Hue-Saturation Fusion Approach to Image Fusion With a Tradeoff Parameter", IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 44, NO. 6, JUNE 2006
2. Te-Ming Tu, Ping S. Huang, Chung-Ling Hung, and Chien-Ping Chang, "A Fast Intensity-Hue-Saturation Fusion Technique With Spectral Adjustment for IKONOS Imagery," Geosciences And Remote Sensing Letters, Vol. 1, no. 4, October 2004.
3. W. J. Carper, T. M. Lillesand, and R. W. Kiefer, "The use of intensity-hue-saturation transformations for merging SPOT panchromatic and multispectral image data," Photogramm. Eng. Remote Sens., vol. 56, pp. 459-467, 1990.
4. Chein-I Chang, "Hyperspectral Data Exploitation: Theory and Applications", Wiley-Interscience, April 2007
5. Gerald Curtis F., Patrick O. Wheatley, "Applied Numerical Analysis", Pearson Addison Wesley

Tab.1 Compare with fusion results

		New method	Fused of IHS	t=2	t=3	t=4	t=5
MSE	G	88.3904	233.7141	124.4730	135.4853	150.5585	162.6007
	R	111.8666	213.5442	189.6159	172.3529	173.2372	176.7844
	NIR	192.5255	407.5397	163.6691	219.5342	257.0178	282.5119
	SWIR	163.2034	365.5485	138.6565	188.8534	223.5304	247.3705
PSNR	G	28.6668	24.4440	27.1801	26.8119	26.3537	26.0196
	R	27.6438	24.8359	25.3521	25.7666	25.7444	25.6564
	NIR	25.2859	22.0291	25.9911	24.7158	24.0312	23.6204
	SWIR	26.0035	22.5014	26.7114	25.3696	24.6374	24.1973
CC	G	0.9287	0.9120	0.9077	0.9156	0.9165	0.9164
	R	0.9482	0.9387	0.9121	0.9280	0.9327	0.9348
	NIR	0.7704	0.5765	0.7779	0.7133	0.6781	0.6569
	SWIR	0.8420	0.7651	0.8627	0.8399	0.8173	0.8069
Bias	G	-0.1711	5.4154	2.7065	3.6088	4.0639	4.3312
	R	-0.1714	5.4339	2.7074	3.6112	4.0677	4.3360
	NIR	-0.1716	5.4126	2.7056	3.6090	4.0634	4.3298
	SWIR	-0.1711	5.4133	2.7064	3.6081	4.0632	4.3308