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Image Fusion and Evaluation by using Mapping Satellite-1 Data

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Abstract

China's Mapping Satellite-1, developed by the China Aerospace Science and Technology Corporation (CASC), was launched in three years ago. The data from Mapping Satellite-1 are able to use for efficient surveying and geometric mapping application field. In this paper, we fuse the panchromatic and multispectral images of Changchun area, which are obtained from the Mapping Satellite-1, the one that is the Chinese first transmission-type three-dimensional mapping satellite. The four traditional image fusion methods, which are HPF, Mod.IHS, Panshar and wavelet transform, were used to approach for effectively fusing Mapping Satellite-1 remote sensing data. Subsequently we assess the results with some commonly used methods, which are known a subjective qualitative evaluation and quantitative statistical analysis approach. Consequently, we found that the wavelet transform remote sensing image fusion is the optimal in the degree of distortion, the ability of performance of details and image information availability among four methods. To further understand the optimal methods to fuse Mapping Satellite-1 images, an additional study is necessary.

Keywords : Mapping Satellite-1, Image fusion, HPF, Mod.IHS, Panshar, Wavelet transform

1. INTRODUCTION

The Mapping Satellite-1 is the Chinese first transmission-type three-dimensional mapping satellite. In August 2010, the Mapping Satellite-1 equipped with three-line array panchromatic sensor (5m resolution), high-resolution panchromatic sensor (2m resolution), and 4-band multi-spectral sensors (10 m resolution) was launched. And the data it collected can be applied in many fields of science such as sientific research, land resources survey, mapping. Table 1 is the sensor that is equipped in Mapping Satellite-1 and the band parametric.

Table 1. Sensors in Mapping Satellite-1 and band parametric

Image category		Wave band (μm)
Panchromatic		0.51~0.69
Multispectral	Blue	0.43~0.52
	Green	0.52~0.61
	Red	0.61~0.69
	Near-infrared	0.76~0.90

Modern remote sense technics tends to apply the high-spectrum and high-resolution sensor. However, it is difficult to achieve both the high-spectrum data and high-

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resolution data of an image simultaneously. To enhance the effectiveness of the application of the remote sensing data, the multispectral data of a sensor or the various data provided by different sensors should be connected by data fusion, which improves the reliability and timeliness of the remote sensing data. In this paper, we perform the image fusion of images of level 1B obtained from Mapping Satellite-1 and evaluate the results.

2. REMOTE SENSING IMAGE FUSION METHODS

Remote sensing image fusion is a technique based on advanced image processing multi-source remote sensing image. It chooses the optimal band combination and resolution based on the type and complexity of environmental conditions, designing the most appropriate phase superposition and combining the advantages of the various images or complementary by using a certain mathematical algorithm to generate the new image that the user needs (Weng, 2003) After the image fusion, not only the visual quality is improved, but also the fusion image has higher spectral and spatial resolution, effectively improving geometric accuracy, the image feature recognition accuracy, and the classification accuracy and providing a good basis for large-scale remote sensing applications research. At present, there are different image fusion methods in different common processing software. For example: ERDAS Imagine uses HPF (High-Pass Filter, High-pass filtering), Mod.HIS uses wavelet transformation, PCI uses Pansharp.

2.1. HPF

The basic principle of remote sensing image fusion by HPF method is relatively simple. For remote sensing image, high-frequency and low-frequency component contains the image of the spatial structure and spectral information, respectively. Thus the data fusion of low resolution/multi-spectral images and high resolution/full-color images can be achieved by getting the details of the structure of high-resolution images through a high-pass filtering operator and using the method of combining pixels to superimpose the details on the low-resolution images (Chavez *et al.*, 1991). Here is the specific fusion formula of HPF:

$$F_{i,j}^{k} = M_{i,j}^{k} + HPH_{i,j} \tag{1}$$

In Eq. (1), $F_{i,j}^{k}$ represents converged value of the pixel (i, j) of the band k, $M_{i,j}^{k}$ is the value of the pixel (i, j) low resolution/multi-spectral image in the band k. $HPH_{i,j}$ denotes the value of the high-frequency image pixel (i, j) obtained by filtering high spatial resolution image with a high-pass filter.

The advantage of HPF lies in the simplicity of algorithm, resulting in the amount of calculation is small, and no limits on band number. So the advantage of this method is that the fused image spatial resolution has been greatly improved and simultaneously the details of the multi-spectral image are fully maintained. But the fused image still contains a relatively large noise.

2.2. Mod.IHS

The colors of the image are usually expressed in two modes, which are three primary colored modes that contains red (R), green (G), blue (B) and colors three-attributes mode constituted by the brightness (Intensity), hue (Hue), and saturation (Saturation). The method of IHS is to separate three components that are the lightness of a color (I), hue (H) and saturation (S) from the RGB image with the transformation of the color images constituted by the red/green/blue and then to use isolated image brightness and high-resolution image data to perform simple placement or appropriate algorithm-calculation, receiving a component. Subsequently Separated replace the image brightness with the calculated component. Eventually inversely transform the replaced lightness (I'), hue (H') and saturation (S') three-component image the second time and generate the RGB data.

The entire process of IHS method can be expressed by the following formula(Tu *et al.*, 2001):

$$\begin{bmatrix} R_{new} \\ G_{new} \\ B_{new} \end{bmatrix} = \begin{bmatrix} 1 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 1 & \sqrt{2} & 0 \end{bmatrix} \begin{bmatrix} Pan \\ \upsilon 1_0 \\ \upsilon 2_0 \end{bmatrix} = \begin{bmatrix} R_0 + \delta \\ G_0 + \delta \\ B_0 + \delta \end{bmatrix} \tag{2}$$

In this formula, $\delta = Pan - I_0$, I_0 represents a luminosity component of low-resolution images. R_0, G_0, B_0, $\upsilon 1_0$ and $\upsilon 2_0$ are the corresponding components of the original multi-spectral image after resampling, respectively. IHS method is simple and can enhance the saturation of the fusion results, thereby improving the color quality of the image and the ability to distinguish. But there is the color distortion. To solve this problem, many scholars put forward some suggestions for improvement IHS fusion method(Siddiqui, 2003).

2.3. Pansharp

Pansharp fusion method is based on the relationship between the gray value of the original multi-spectral image and the original panchromatic which is calculated by the least squares approximation method(Zhang, 2002). Adjustment of a single band of gray distribution can reduce the color deviation of the fusion results. Also, a series of statistical processing of the input of all bands can eliminate the dependence of the fusion results on the data and can improve the degree of automation of the process of integration.

2.4. Wavelet Transform

The wavelet transform is a localization analysis of the frequency of time (space). It multi-scale refines the signal (function) step-by-step through the telescopic shifting, and eventually achieves subdivision at high frequency at the time and the subdivision at low frequency that can automatically adapt to the requirements of time-frequency signal analysis. The wavelet transform can be focused on any details of the signal and wavelet transform is called "mathematical microscope”. Traditional wavelet transform fusion method uses the wavelet transform to transform the image from the spatial domain to the frequency domain, which means detail component of the high spatial resolution of the panchromatic image replaces the detail component of the low spatial resolution of the spectral image. Then inversely wavelet transform the wavelet coefficients of the spectral image and obtain the fusion image. Specific steps are as follows:

(1) Registrate the image that needs to be fused, and ensue the accuracy of the registration within one pixel;
(2) Apply wavelet transform n times (n is usually 3 or 4) on the high-frequency image and low-frequency image respectiveiy to obtain the low frequency contour image and the high-frquency detail image;
(3) Replace the high-frequency detail image with the high-frequency part of the full-colour image;
(4) Use the inverse wavelet transform to process the low-frequency contour image and the high-frequency part of the full-color image, and obtain the fusion image.

3. FUSION QUALITY EVALUATION METHODS

The purpose of remote sense image fusion is to increase the readability of images through the integration of high spatial resolution panchromatic image and low spatial resolution multispectral images on a promise of reducing the original image information amount as less as possible. The readability of images means the fusion image has advantages of both panchromatic and multi-spectral image, which are high spatial resolution and rich colors. Therefore, the quality of the fused image can be defined as the image spatial resolution and spectral information.

The subjective qualitative evaluation and quantitative statistical analysis approach usually assess image fusion quality. Subjective qualitative evaluation relies on the human eye subjective assessment, which means according to the purpose of the application in the fused image the data that highlights the desired information is the best. And quantitative statistical analysis focuses on the mean, standard deviation, entropy, average gradient, correlation coefficient and the deviation index indicators of the fused image(Huang *et al*., 2013a, b).

Specific details are as follows:

(1) Mean of images: The mean is the average of the gray values, which is the average luminance of the human eye. The gray-scale value 128 can be regarded as a good visual effect.
(2) Standard deviation: Standard deviation is often used

as an important indicator to measure the amount of image information and it reflects the degree of dispersion that the gray values deviate from the image mean. It is an important parameter to measure the amount of information of an image. If the standard deviation of the image is large, the image gray level of dispersion increases, the image contrast is obvious and information contained is rich, and vice versa.

(3) Information entropy: In accordance with the principles of the Shannon information theory that entropy values can reflect the amount of information on image fusion results. Entropy is an important indicator about whether the information of image is rich. The greater entropy of the fused image indicates that the images carry more information and the quality of fusion images is better.

(4) Average gradient: Sensitively reflect the ability of the image to express the contrast on the minute details. Therefore it can be used to evaluate the clarity of the image.

(5) Spectral correlation coefficient: Spectral correlation coefficient reflects the spectral characteristics similarity between the resulting images and the original multispectral images.

(6) Spectral deviation index: Spectral deviation index is the degree the results maintain on the spectrum of high-resolution images. When the deviation index is low, the degree of deviation from the fusion image with the original multi-spectral image is small.

The evaluation parameters used in the statistical analysis of the quantitative formula are shown in Table 2. F_k and M_k represents the brightness value on the band-k on the same pixel in the results and the Multispectral images, respectively. $\overline{M}_k$, $\overline{F}_k$ represents the mean brightness value in the range of $n \times m$. BV is the brightness value of the $\overline{M}_k$, $\overline{F}_k$.

4. EXPERIMENTAL RESULTS AND EVALUATION

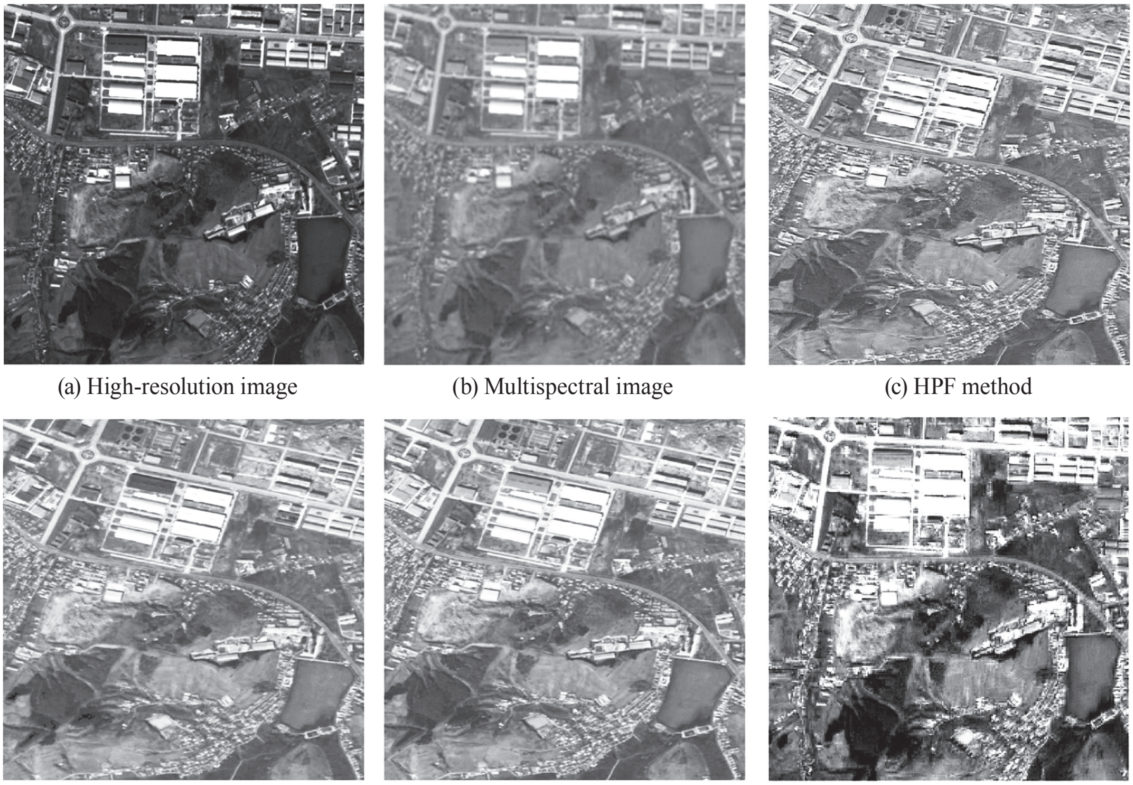
The principal objective of fusion in remote sensing is to obtain high-resolution multispectral images that can combine the spectral characteristic of the low-resolution multispectral images with the spatial information of the high-resolution panchromatic images(Denipote and Paiva, 2008). In this experiment step, the Image fusion results using Mapping Satellite-1 data were evaluated through visual effects and quantitative statistics, respectively. Changchun,the research area, is located the northeast of the China and is the capital and largest city of Jilin province.

Table 2. Quantitative statistical analysis of indicators and formulas(Shi *et al.*, 2005)

Evaluation parameters	Formulas
Mean	$\mu = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n} F(i,j)$
Standard Deviation (SD)	$\sigma = \sqrt{\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(BV(n,m)-\mu)^2}{m \times n}}$
Entropy (En)	$En = -\sum_{0}^{I-1} P(i)\log_2 P(i)$
Average Gradient (AG)	$G = \frac{1}{(m-1)(n-1)}\sum_{i=1}^{m}\sum_{j=1}^{n}\sqrt{\frac{\left(\left(\frac{\partial Z(x_i,y_j)}{\partial x_i}\right)^2 + \left(\frac{\partial Z(x_i,y_j)}{\partial y_j}\right)^2\right)}{2}}$
Correlation Coefficient (CC)	$CC = \frac{\sum_i^n\sum_j^m (F_k(i,j)-\overline{F}_k)(M_k(i,j)-\overline{M}_k)}{\sqrt{\sum_i^n\sum_j^m (F_k(i,j)-\overline{F}_k)^2}\sqrt{\sum_i^n\sum_j^m (M_k(i,j)-\overline{M}_k)^2}}$
Deviation Index (DI)	$DI_k = \frac{1}{nm}\sum_i^n\sum_j^m \frac{\lvert F_k(i,j)-M_k(i,j)\rvert}{M_k(i,j)}$

4.1. Visual Effects Analysis

As is shown in Figure 1, it can be seen from the overall visual effect that the spatial resolution of the high-resolution multi-spectral images after fusion significantly improved, and the images are clearer and more easily identified than before. In terms of texture details, the contents of the image after fusion are richer than the original multi-spectral image texture, and clarity and spatial detail are greatly improved. The linear features such as land and house edge becomes apparent after fusion. The image processed by HPF performs well on texture detail; wavelet



(a) High-resolution image (b) Multispectral image (c) HPF method

(d) Mod. IHS method (e) Pansharp method (f) Wavelet transform method

Fig. 1. uses images (a, b) and the results are (c, d, e, f)

transform has loss on some texture details, because in the wavelet transform fusion process, some details of a high resolution image were lost. However, the images after wavelet transform fusion have higher image contrast, and can be identified more easily.

In terms of spectral characteristics, the spectral information of images after wavelet transform fusion are preserved best and the color is closest to the original multispectral images. The HPF and Pansharp perform second, the IHS proferms worst among the four methods.

Above all, images processed by wavelet transform have the best resolution and can be identified easily while the brightness and contrast of these images are also the best. So wavelet transform is the optimal method. Although the HPF performs best on details, the ability to maintain the spectral information of the images is weak, and IHS perform worst on details and maintenance of spectral information.

4.2. Quantitative Statistical Analysis

In this experiment, we use mean of images, standard deviation, information entropy and average gradient to evaluate the effect of the four methods on the improvement of the spatial information and the maintenance of spectral information. The results are as follows.

From Table 3, in terms of brightness, the mean of HPF is the highest, which is the softest on visual. Standard deviation and information entropy represent the total amount of information. And the wavelet transform preforms better than the other three methods on these two standards. On clarity, the mean of gradient value based on the wavelet transform method surpasses other three. HPF is the second. On spectral information, the performance of wavelet transform on maintenance of spectral information is the best, and it means the wavelet tranform can maintain the most spectral information.

According to quantitative statistical tables of the

Table 3. The evaluation statistics of the fusion methods

Assessment content		luminance information	Quantity information		Clarity	Spectral information	
Fusion method	Wave band	Mean	SD	En	AG	CC	DI
HPF	R	146.34	46.18	4.89	38.84	-0.071594	2.855483
	G	126.41	33.32	4.48	29.57	0.020147	2.336828
	B	114.61	28.45	4.31	26.80	-0.016387	2.079173
Mod.IHS	R	106.01	59.67	4.05	7.01	0.185712	1.216882
	G	102.24	58.01	3.96	6.96	0.213950	1.045357
	B	93.37	55.28	3.78	7.83	0.251250	1.053091
Pansharp	R	104.71	60.52	4.10	7.35	0.222235	1.170055
	G	101.26	60.14	4.03	7.41	0.252615	1.001334
	B	94.85	58.34	3.90	7.39	0.285214	1.026775
Wavelet transform	R	119.91	61.92	4.95	58.43	0.018813	1.623400
	G	84.98	42.75	4.79	42.48	0.026705	1.056338
	B	64.10	37.76	4.63	38.70	0.103590	0.958403

integration quality of image, the values, which include the average gradient, entropy and spectral correlation coefficient, of the images processed by the wavelet transform are the best among all four methods. And it means that compared with the other three methods, wavelet transform performs best on the degree of distortion, the ability of presentation of details and total amount of image information preserved. Thus we can conclude that wavelet transform method is the optimal method.

5. CONCLUSION

In this paper, we used four traditional fusion methods to fuse the panchromatic and multispectral images of Changchun, which is obtained from Mapping Satellite-1, the one that is the Chinese first transmission-type three-dimensional mapping satellite. Through the comparison on the results, we found the most optimal method. Because of the richness and complicity of data as well as the purpose, there are still many problems. Every method has its own advantage and disadvantage. This paper shows that the wavelet transform is the best on the correlation coefficient, the average gradient and information entropy. But its performance on local texture detail is poor. So for the multi-source remote sense data fusion, we should consider the purpose and regional characteristics of image features. To further understand the optimal methods to fuse Mapping Satellite-1 images, an additional study is necessary.

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