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Comparison of Fusion Algorithms for ALOS Panchromatic and Multispectral Images

X. Chen, J. Wu, Y. Zhang
College of Environmental & Resources Sciences
Zhejiang University
Hangzhou, China
chenxia198609@yahoo.cn

***Abstract*—Image fusion techniques of remote sensing data can integrate different spatial and spectral information. ALOS is a new data source with two optical sensors onboard, PRISM and AVNIR-2. PRISM has high spatial resolution, while AVNIR-2 is of multi-spectral resolution. Study on ALOS data fusion methods has potentials for promoting the applications of ALOS data. This paper aimed to explore a proper method for data fusion purpose. Five fusion methods, Brovey, PCA, SFIM, HPF and Gram–Schmidt, were tested. Visual and statistical comparisons were conducted to evaluate the effect of different fusion algorithms in terms of spatial resolution enhancement and spectral information maintenance. We found overall results of Gram–Schmidt in improving spatial resolution details and preserving spectral information were superior to the others. PCA was good at enhancing textural information, but caused much color distortion. SFIM best preserved the spectral abundance, but was less optimal at improving spatial information.**

Keywords-ALOS, Image fusion, Comparison, Gram–Schmidt

I. INTRODUCTION

The Advanced Land Observing Satellite (ALOS) was successfully launched by the Japan Aerospace Exploration Agency (JAXA) on January 24, 2006. ALOS is one of the largest earth observing satellites. It has three sensors: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) that measures precise land elevation; the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) that observes what covers land surfaces, and the Phased Array type L-band Synthetic Radar (PALSAR) that enables day-and-night and all-weather land observations. So far, all operations are in healthy condition [1].

For the purposes of photograph analysis, feature extraction, modeling, and classifications, image fusion methods of remote sensing data aim at integrating the information acquired with different spatial and spectral resolutions [2]. Various methods have been developed and utilized to merge complementary digital image covering same geographical area [3]. As a new source of high resolution data source, study on ALOS image fusion methods is of significance in promoting extensive applications of the data.

At present, Principle Component Analysis (PCA), Smoothing Filter-based Intensity Modulation (SFIM), High Pass Filter (HPF), Brovey transform, Multiplicative, Wavelet decomposed (DWT) and Gram-Schmidt (GS) are among the five general fusion algorithms on pixel-level image. These five methods were selected in this study to fuse high resolution PRISM Panchromatic data into multi-spectral AVNIR-2. Their performance was evaluated qualitatively and quantitatively in terms of the enhancement on spatial resolution and the maintenance of spectral information.

II. STUDY AREA AND DATA PREPROCESSING

The PRISM panchromatic data used in the study had a spatial resolution of 2.5m, while the multispectral data by the AVNIR-2 sensor of ALOS had three visible bands and one infrared band, but a spatial resolution of 10 m. They were both collected on November 29, 2007. The study area, with the longitude of 119.68E and the latitude of 30.68N, was in Anji County, situated in the northwest of Zhejiang Province, China. It includes water body, vegetation, road and town, has universal representation.

The preprocessing procedure, mainly geometric correction, is very important to any data fusion work. The fusion by pixel has advantages as the images can use the most original information [2]. In the preprocessing procedure, the multi-spectral image is geometrically rectified to the panchromatic image. The images are co-registered at the sub-pixel accuracy, and the multispectral image is re-scaled to match the panchromatic image so that they are of the same pixel size. A bilinear interpolation method is used for image transformation.

III. IMAGE FUSION TECHNIQUES

Among the five fusion algorithms tested in this study, Brovey, PCA and HPF transformations are implemented in ERDAS IMAGINE in the Interpreter procedure, GS transformation in ENVI in the Transform procedure, and SFIM transformation in MATLAB through programming according to its algorithm. The processing was done in double precision arithmetic, and the output images were stored in the same format as the input raster data.

A. Fusion method based on Brovey transformation

Brovey transformation is a simple numerical method to merge different sources of data. Brovey equation is designed on the basis of the assumption that spectral range of the panchromatic image is the same as that covered by multispectral data. As Brovey transformation can only deal with three bands of multispectral image, the study choose the 4^{th}, 3^{th} and 2^{th} band of the AVNIR-2. The fused image consists of a combination of the three bands of multispectral

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image and the panchromatic image. The algorithm is defined as below:

$$Y_k(i,j) = \frac{X_k(i,j) \cdot X_p(m,n)}{\sum_{k=2}^{4} X_k(i,j)}$$

where $Y_k(i,j)$ and $X_k(i,j)$ are the kth fused multispectral band and the original multispectral band respectively, i and j are the pixel number and line number of the kth multispectral bands; $X_p(m,n)$ is the original panchromatic band, m and n are the pixel and line numbers of panchromatic band data, respectively.

B. Fusion method based on Principal Component Analysis (PCA)

The principal component transformation [4], whose aim is to filter out redundant information in the original satellite channels is a method frequently used for information concentration in remote sensing. Principal components are synthetic channels generated by a rotation within the feature space. By a rotation and shift of the original coordinate systems in bi-dimensional feature space, the principal components are concentrated along the maximum variance. Generally, the first three principal components contain 95% of the total variance. A high proportion of the information is concentrated in the first principal component.

In the process, four principal components are generated from the AVNIR-2 by principal component transformation; by a fitting procedure, the PAN gets the same gray mean and variance with the first principal component, which contains the major fraction of the total variance; an inverse principal component transformation is then performed with the fitted PAN and the three remaining principal components. In this inverse transformation, an automatic resampling of the second, third and fourth principal component is performed at the same time.

C. Fusion method based on High Pass Filter (HPF)

The HPF algorithm enhances the spatial resolution of low-resolution multispectral data by adding the spatial to the spectral information [5, 6].

In the process, Firstly, the high spatial resolution image is fused in advance with a small high pass filter(5×5 in the study) to highlight the linear features and edge information of the image, because this process can effectively obtain the higher frequency information which represents the space characteristics. Secondly, the low spatial resolution image is fused in advance with a small low pass filter (5×5 in the study) to obtain the lower frequency information which represents the spectral characteristics of the image. At last, the filtered images are subsequently calculated according to the algorithm defined as below:

$$IMAGE_{HPF_i} = \frac{IMAGE_{high_i} + IMAGE_{low_i}}{2}$$

where $IMAGE_{HPF_i}$ is the ith band of fused high resolution image, $IMAGE_{low_i}$ is the ith band of low-resolution image in advance using a small low-pass filter, and $IMAGE_{high_i}$ is high-resolution image processed in advance using a small high-pass filter. The result is then divided by two to offset the increase in DNs.

D. Fusion method based on Gram–Schmidt (GS)

The Gram-Schmidt transformation [4, 7] is a common method in linear algebra and multivariate statistics. GS functions in a similar manner to the PCA, also with the aim of minimizing redundancy. However, in this case, the main component transformation is replaced by a Gram–Schmidt orthogonalization.

In the process, firstly, a simulated lower spatial resolution panchromatic band is generated, by which the first multispectral band is replaced. Then the regrouped multispectral bands are subjected to Gram–Schmidt transformation. Secondly, by comparing the statistics of the first Gram–Schmidt component with the statistics of the original panchromatic image, a modified pan band of higher spatial resolution is generated, by which the first of the Gram–Schmidt components is replaced. At last, the fused image is obtained via an inverse application of the Gram–Schmidt transformation.

E. Fusion method based on Smoothing Filter-based Intensity Modulation (SFIM)

The SFIM [8] is a ratio method that the high-resolution image is divided by a simulated low-resolution image and the result is then multiplied by the low-resolution image. SFIM is developed based on the principle of the solar radiation and the spectral reflectance of the land surface. The algorithm is defined as below:

$$IMAGE_{SFIM_i} = \frac{IMAGE_{low_i} \times IMAGE_{high}}{IMAGE_{mean}}$$

Where $IMAGE_{SFIM_i}$ is the ith band of fused high-resolution image; $IMAGE_{low_i}$ is the ith band of low-resolution input image, co-registered to a high-resolution input image $IMAGE_{high}$; and $IMAGE_{mean}$ is a simulated low resolution image derived from $IMAGE_{high}$ using an averaging filter(5×5 in the study) for a neighborhood equivalent to the resolution of $IMAGE_{high}$.

SFIM can be understood as a 1ow-resolution image modulated directly by high spatial frequency information and the resulting image is independent of the contrast and spectral properties of the higher resolution image, as the ratio between $IMAGE_{high}$ and $IMAGE_{mean}$ in the equation cancels the spectral and topographical contrast of the higher resolution image, but retains its higher resolution textures. What should be specially pointed out is that SFIM is not applicable for fusing images that are fundamentally different in illumination conditions or physical properties, such as the fusion between optical images and radar images or geophysical/geochemical data.

IV. RESULT

Different fusion algorithms were employed to merge the high spatial resolutions PRISM image into AVNIR-2 with rich spectral information. The suitability of these images for various applications depends on the spectral enrichment and spatial precision existing in the fused images. Hence, it is necessary to quantitatively assess these pan-sharpened images [9]. In general, qualitative and quantitative quality metrics were often used to evaluate image quality [10].

A. *Qualitative visual comparison*

To compare the fidelity of different fusion method, two small sub-scenes were cropped. The original images and different fusion images were shown in Fig. 1 and Fig. 2.

In sub-scene 1, initial qualitative visual inspection reveals that textural details are greatly highlighted after fusion, the spatial texture are distinctly clear and apparent in fused images while vague in the original image. Although the improvement of spatial information is not much different in five methods, there is a large discrepancy in spectral fidelity. The PCA causes the most severe color distortion, and the image becomes darker when Brovey method was used. In terms of fidelity, the HPF is good, the GS is better, and the SFIM is the best. We obtain the similar results from Fig. 2.

B. *Quantitative comparison of parameters*

In addition to the visual inspection, a quantitative analysis was conducted in terms of information improvement and fidelity of spectral characteristics. The results were evaluated using the quantitative parameters in TABLE 1.

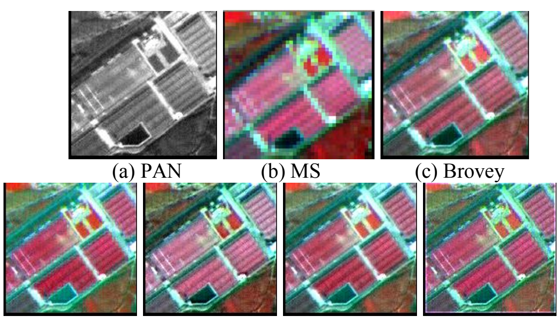
(a) PAN (b) MS (c) Brovey (d) PCA (e) HPF (f) GS (g) SFIM

Figure 1. Visual comparison of original and fused images of sub-scene 1

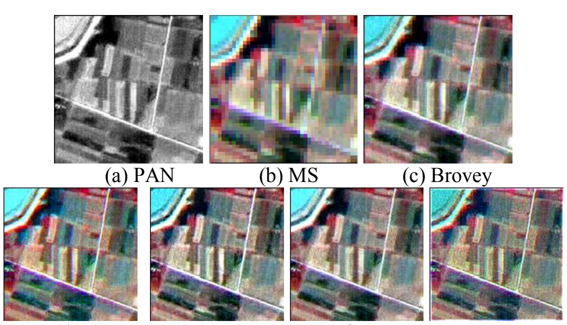
(a) PAN (b) MS (c) Brovey (d) PCA (e) HPF (f) GS (g) SFIM

Figure 2. Visual comparison of original and fused images of sub-scene 2

TABLE I. PARAMETERS FOR QUANTITATIVE COMPARISON

Item	Equation	Remark
Entropy	$E(x) = -\sum_{i=1}^{L-1} p_i \log_2 p_i$	P_i probability
Average	$\overline{Z} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} Z(x_i, y_j)$	
Standard error	$std = \sqrt{\frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (Z(x_i, y_j) - \overline{Z})^2}{MN}}$	$Z(x_i, y_i)$ image data
Average Grads	$\overline{G} = \frac{1}{(M-1)(N-1)} \sum_{i=1}^{M-} \sum_{j=1}^{N-1} \sqrt{\frac{((\frac{\partial Z(x_i, y_i)}{\partial x_i})^2 + (\frac{\partial Z(x_j, y_j)}{\partial y_j})^2)}{2}}$	
Bias	$D = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \lvert F(x_i, y_i) - A(x_i, y_j) \rvert$	$A(x_i, y_i)$ original image
Correlation coefficient	$R_{FA} = \frac{I = \sum_{i=1}^{M} \sum_{j=1}^{N} [F(x_i, y_j) - \overline{f}] \cdot [A(x_i, y_j) - \overline{a}]}{\sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} [F(x_i, y_j) - \overline{f}]^2 [A(x_i, y_j) - \overline{a}]^2}}$	$F(x_i, y_i)$ fusion image

These parameters provided effective means to assess the quality of those fused images generated from the various algorithms. Among the quantitative index, entropy, average grads, standard error and correlation coefficient with PRISM were the parameters to quantify spatial information, while the average, bias and correlation coefficient with AVNIR-2 were the ones to quantify spectral information. Quantitative comparisons of all the factors for the various algorithms were shown in Fig. 3.

As shown in Fig. 3-a, the entropy of fused images was generally greater than that of the original one. This means that the amount of information of the PRISM incorporated into AVNIR-2 during the merging was increased, especially by GS and PCA methods. From Fig. 3-b, we can learn that the standard errors of all the bands become large except band 4. According to the statistics, the standard error increased from Brovey, HPF, SFIM, PCA to GS in sequence. The trend of increment for the average grads (see Fig. 3-c) was almost the same as that of the standard error. The correlation coefficient between fusion image and PRISM (Fig. 3-d) also showed that GS was the best. In other words, GS was the best in terms of all the spatial information indicators evaluated. PCA, though less optimal than GS, was still a good one among the five methods. This illustrated that GS and PCA methods were superior to the other three in improving spatial information for ALOS imagery.

In Fig. 3-e, the average became much smaller by Brovey fusion, so the fused image was much darker than AVNIR-2. There were slightly difference in average between AVNIR-2 and other fused images, especially in the GS method. It could be obviously found from Fig. 3-f and Fig. 3-g that SFIM was the best in both bias and correlation coefficient with AVNIR-2 which was followed by the GS method. All of these results indicated that the general outcomes of SFIM and GS were better than the others in preserving spectral information, and SFIM was slightly better than GS.

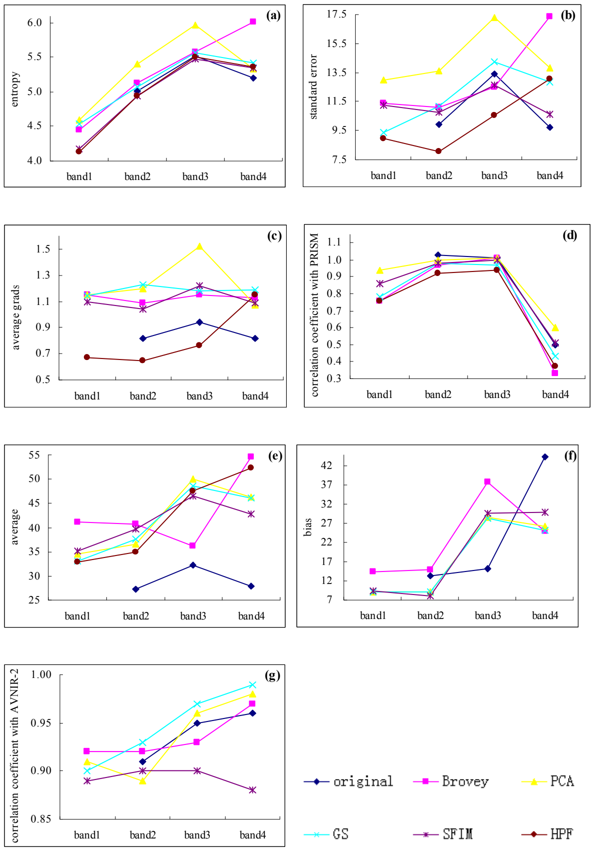

Figure 3. Entropy (a) , standard error (b) , average grads (c) , average (e) of each band of AVNIR-2 and fused images; correlation coefficient of each band of fused images with PRISM (d); Bias (f); Correlation coefficient of each band of fused images with AVNIR-2 (g) .

Consequently, the GS method was superior to the others for ALOS imagery fusion because it not only enhances spatial information effectively, but also preserves spectral information contained in the original AVNIR-2 imagery.

V. SUMMARY

This study evaluated the five frequently used fusion methods by merging PRISM panchromatic (2.5m resolution) into AVNIR-2 multispectral (10m resolution) data. According to the visual inspection and the six indicators (entropy, average, standard error, average grads, bias and correlation coefficient), all the methods improved the resolution and features presented in the fused multispectral image. The quantitative comparison of the five methods showed that Gram–Schmidt was superior to the other fours in improving spatial resolution and preserving spectral information. PCA was good at enhancing textural information, but caused much color distortion. SFIM best preserved the spectral information, but was less optimal at improving spatial resolution.

VI. ACKNOWLEDGEMENT

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