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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (22): 6694-6701, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.6694.6701

Study on the Hyperspectral Image Fusion Based on the Gram_Schmidt Improved Algorithm

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Abstract: To solve the problems of low spatial resolution and much mixed pixel of traditional hyperspectral image, this paper puts forward a hyperspectral image fusion method based on Gram_Schmidt improved algorithm (GS3), in order to improve the fusion effect of the hyperspectral remote sensing image and high spatial resolution image. It adopts GS3 and other various fusion methods to make fusion comparison experiment on the Hyperion hyperspectral image and ALI panchromatic band of the same time phase and the same sensor (EO-1) and respectively uses the qualitative and quantitative methods to make comprehensive analysis and evaluation of the fusion results. The experimental results show that, compared with other hyperspectral image fusion methods, GS3 method can better maintain the spectral feature and space texture feature of hyperspectral image at the same time, which is a relatively ideal hyperspectral image fusion method.

Key words: Data fusion, hyperspectral image, gram schmidt algorithm, panchromatic band

INTRODUCTION

For space optical remote sensing sensors, the spectral resolution and spatial resolution of remote sensing image are a pair of contradictions. For example, EO-1 Hyperion image has very high spectral resolution (the theoretical band number is 242 and the spectral resolution is 10 nm) but its spatial resolution is relatively low (only 30 m). In the remote sensing surface feature classification application, although hyperspectral image has hundreds of fine bands, which has strong surface feature recognition ability, yet the area that each pixel covers is larger (30×30 m^2) and the mixed pixel is much, while the pure is less. The surface feature classification accuracy is hard to further improve, so the situation of simply using hyperspectral image for surface feature classification is rare. The fusion of hyperspectral image and high space resolution image can effectively solve the problem and the two can complement each other. In the situation of improving and maintaining hyperspectral image space feature and spectral feature, it also can replace or repair the defect of image data, especially the introduction of surface feature texture information in high space resolution image, so as to greatly improve the classification accuracy of hyperspectral image (Yu *et al*., 2007). This study puts forward a hyperspectral image fusion method based on Gram_Schmidt improved algorithm (GS3), in order to improve the fusion effect of hyperspectral remote sensing image and high spatial resolution image.

HYPERSPECTRAL IMAGE FUSION METHOD BASED ON GRAM-SCHMIDT

Gram-Schmidt (GS) algorithm is a common method in linear algebra and multivariate statistics and the method conducts orthogonals to eliminate redundant information on the matrix or multidimensional images (Clayton, 1971). The existing related research data shows that GS fusion method is an ideal fusion method of hyperspectral and high spatial resolution remote sensing image. Compared with other algorithms, it has obvious advantage in maintaining original image spectral information and improving its clarity aspect (Lin, 2013). The hyperspectral image fusion process based on GS algorithm is as shown below in Fig. 1 (Li *et al*., 2004a).

As known from Fig. 1, in the GS transform fusion of remote sensing image, it first adopts appropriate low resolution hyperspectral image or registered high resolution panchromatic image to simulate low spatial resolution panchromatic image, then it conducts GS transformation for the above mentioned simulated panchromatic image and hyperspectral image. It takes the simulated low spatial resolution panchromatic image as the first component of GS transformation orthogonal vector, calculating and according to the component related feature value to modify high spatial resolution panchromatic image's feature value and making the both statistical features match. The modified high spatial resolution panchromatic image replaces the first

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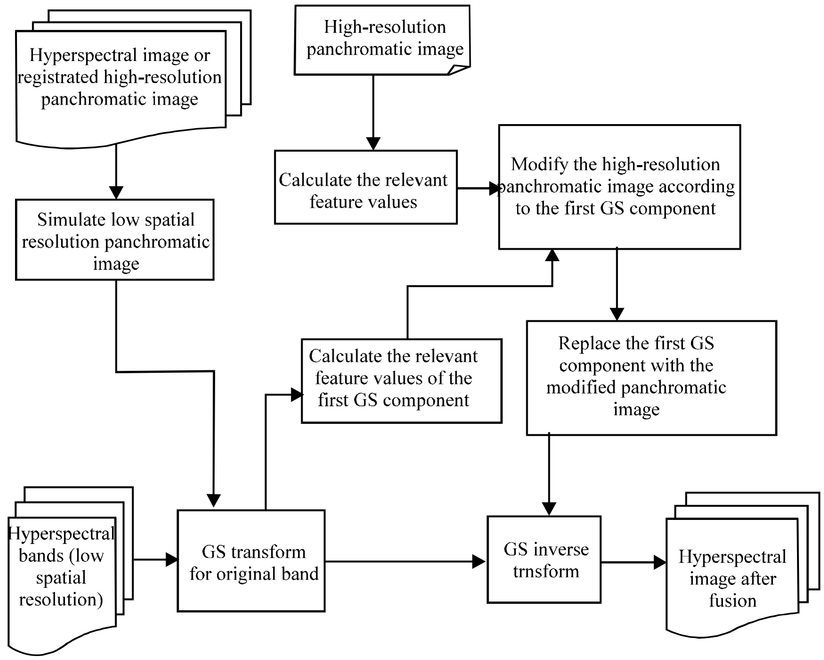

Fig. 1: Hyperspectral image fusion process based on GS algorithm

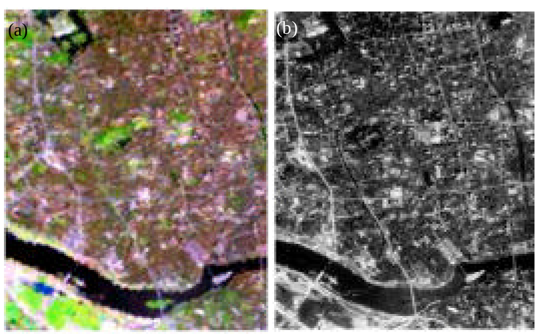

Fig. 2(a-b): Hyperion hyperspectral image and ALI panchromatic image of the experimental area 1, (a) Hyperion and (b) Ali-Pan

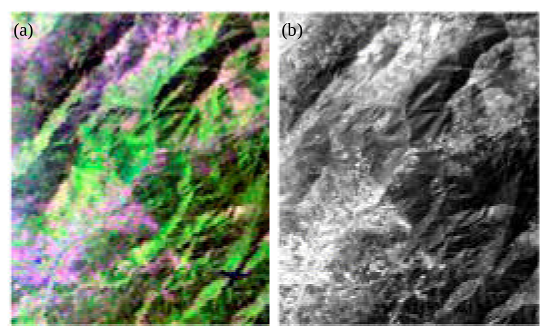

Fig. 3(a-b): Hyperion hyperspectral image and ALI panchromatic image of the experimental area 2, (a) Hyperion and (b) Ali-Pan

component of GS transformation and other components are unchanged. Finally, conducting GS inverse transformation can obtain the final fusion image.

THE HYPERSPECTRAL IMAGE FUSION METHOD BASED ON GS IMPROVED ALGORITHM

In GS transformation, the first component simulated image quality has greater influence on fusioned image quality, which is also the key of GS transformation fusion method. The simulation methods are generally two methods: Method 1(GS1), through directly calculating n spectral bands' average value for simulation (Yu *et al*., 2007); method 2(GS2), high spatial resolution panchromatic image is processed through low-pass filtering or local mean treatment (Liu, 2000), through resampling makes it have similar resolution and the same size of multispectral image. In order to improve the quality of fusion image, to achieve better spatial information enhancing effect and ensure higher spectral fidelity, this study proposes a new GS transformation first component simulation image generating method based on normalized weight index (GS3), through conducting weighted average and resampling of the hyperspectral image's related bands, simulating panchromatic low resolution image. The simulation image P is determined by the hyperspectral related band B_i and normalized weighting index W_i and the calculation methods of P and W_i are, respectively as shown in Eq. 1 and Eq. 2 (Li, 2008).

$$P = \sum_{i=1}^{n} B_i \times W_i \tag{1}$$

$$W_i = \frac{\int T(i) \times C(i) \times S(i)}{\sum_{i=1}^{n} \int (T(i) \times C(i) \times S(i))} \tag{2}$$

where, B_i and W_i are, respectively the hyperspectal related band feature value and normalized weight index,T (i) and C (i) are, respectively the transfer function and response function of hyperspectral i band and S (i) is the spectral response function of panchromatic band on i band and n represents hyperspectral band number.

HYPERSPECTRAL IMAGE FUSION EFFECT EVALUTION METHOD

Qualitative evaluation methods: The qualitative evaluation of image fusion effect is mainly from the visual perspective to compare the change situation of image before and after fusion and the main indexes are image brightness, sharpness, edge strength, color uniformity and the similarity with real surface features (Li *et al*., 2004b). The qualitative evaluation of image fusion effect tends to be subjective and uncertain.

Quantitative evaluation methods: Compared with the subjectivity and uncertainty of qualitative evaluation, the quantitative evaluation can more accurately reflect the specific difference of image before and after fusion. For different image fusion purposes, qualitative evaluation indexes of image fusion effect are different. The current mainstream evaluation indexes are mean, standard deviation, entropy, average gradient, correlation coefficient, distortion degree, bias index, mean square root error, mean square error, peak value signal noise ratio, signal noise ratio, calculation space frequency, cross entropy, joint entropy, relative entropy (mutual information), structural similarity, edge strength and ERGAS index etc. (Li *et al*., 2004a). In the research, it chooses 6 evaluation indexes of better reflecting hyperspectral image fusion effect and they are respectively the average gradient (G), correlation coefficient (R), twist degree (NC), deviation index (D), root mean square error (RMSE) and ERGAS index (EGS) and the definitions of the index parameters are as follows:

Average gradient (G): The average gradient (G) is also called as clarity, which mainly reflects the clarity of the image and the small detail contrast and texture transformation features of image (Zhu and Li, 2005). The calculation of average gradient (G) is as shown in the formula below:

$$G = \frac{1}{(M-1)\times(N-1)} \sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{\frac{\Delta xf^2(i,j) + \Delta yf^2(i,j)}{2}} \tag{3}$$

where, xf (i, j), yf (i, j) are, respectively first order difference value of pixel (i, j) in x, y direction; the larger G is, the more the image levels are and the image are clearer (Zhu and Li, 2005).

Correlation coefficient (R): The correlation coefficients mainly reflect the correlation degree of two images. The calculation of average gradient (R) is as shown in the formula below (Lin, 2013):

$$R = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} [S(i,j) - \bar{S}(i,j)][F(i,j) - \bar{F}(i,j)]}{\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} [S(i,j) - \bar{S}(i,j)]^2 \sum_{i=1}^{m} \sum_{j=1}^{n} [F(i,j) - \bar{F}(i,j)]^2}} \tag{4}$$

In the formula, S (I, j) and F (I, j) are, respectively the gray value of original image and fusion image on the i line and the j row. The larger R value is, the correlation degree of fusion image and original image is higher, representing the fusion image can maintain the spectral information of original image better and the fusion quality is higher (Lin, 2013).

Spectral distortion degree (NC): Spectral distortion degree (NC) reflects the spectral unreal degree of image. The calculation of NC is as shown in the formula below (Zhu and Li, 2005):

$$NC(\lambda) = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} \left| G'(\lambda,i,j) - G(\lambda,i,j) \right| \tag{5}$$

where, m and n are respectively the pixel rows and lines of λ band image, G (λ, i, j)and G'(λ, I, j)are respectively the corresponding gray values of λ band before and after fusion. NC (λ) represents the spectral difference of λ band before and after fusion, thus the smaller the value is the better (Xia *et al*., 2002). The spectral correlation coefficient and the spectral twist degree of the two indexes main evaluate the maintaining degree of multispectral information.

Deviation index (D): Deviation index (D) refers to the relative difference of average gray value of fusion image and original image, which reflects the spectral information loss degree of fusion image to the original image (Lin, 2013). The D value is smaller and it means the fusioned image improves the spatial resolution and maintains multispectral image's spectral information better and the deviation index (D) calculation is as shown in the formula below (Lin, 2013):

$$D = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} \left| \frac{F(i, j) - S(i, j)}{S(i, j)} \right| \tag{6}$$

In the formula, S (i, j) and F (i, j) are, respectively the gray value of original image and fusion image on the i line and the j row. The D value is smaller, representing the fusion image information loss degree is smaller, which maintains the spectral information of the original image better and the spectral distortion is smaller.

Root mean square error (RMSE): Root mean square error (RMSE) is also called as the standard deviation, which reflects the difference degree of fusion image and original image (Xia *et al*., 2002). The calculation of RMSE is as shown in the formula below (Xia *et al*., 2002):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{m} \sum_{j=1}^{n} [F(i, j) - S(i, j)]^2}{m \times n}} \tag{7}$$

In the formula, S (i, j) and F (i, j) are, respectively the gray value of original image and fusion image on the *i* line and the j row. The RMSE value is smaller, representing the spectral deviation of fusion image and original image is smaller and the fidelity is higher.

ERGAS index: ERGAS refers to non dimensional index (relative whole dimension comprehensive error) (Yu and Pei, 2012) and the calculation formula is as follows (Jiang *et al*., 2008):

$$EGS = 100 \frac{h}{l} \sqrt{\frac{1}{N} \sum_{i=1}^{N} (RMSE^2(Bi)/Mi^2)} \tag{8}$$

In the formula, h is the resolution of high resolution image, l is the resolution of low resolution image, N is the number of bands, Bi is multispectral image and Mi is the average value of radiation value of multispectral image. Generally speaking, ERGAS mainly evaluates all the fusion bands' spectral quality in the spectral scope, considering the whole situation of spectral change. It value is smaller, which represents in the spectral scope, the spectral quality of fusion image is better (Jiang *et al*., 2008).

EXPERIMENTAL AND RESULT EVALUATION

Experimental area remote sensing image acquisition and preprocessing: This study has a total of two experiment areas. Experimental area 1 is located in the Gulou District, Taijiang District and Cangshan District under the jurisdiction of Fuzhou City and the experimental area is distributed on both sides of Mingjiang. The experimental district belongs to subtropical humid monsoon climate in climate, the district elevation is about 2.5~100 m, with relatively flat terrain. The experimental district is located on Minjiang coast, which is the center district of Fuzhou City, which has buildings, rivers, forests, bare lands, roads and a lot of public facilities. Experimental area 2 is located in the northwest of Fuqing City (county level city) under the jurisdiction of Fuzhou City of Fujian Province coast and the experimental area elevation is about 2500~4300 m, with mountainous terrain. The experimental area is distributed with a lot of forests and a little gardens, cultivated land, bare land, buildings and waters, which are mixed with some shrub grass and burned areas.

The hyperspectral data of two experimental areas adopts Hyperion image (L1G format, altogether 242 bands) obtained by EO-1 sensor and the imaging time is Mar.26th 2003. The image is clear, with cloud amount of 0% and the spatial

Resolution is 30 m and the research district size is 155×230. It obtains the above mentioned two experimental areas' the same sensor and the same time phase EO-1 ALI image panchromatic image and the research area size is 465×690. First, it removes the bands of uncelebrated and greatly affected by moisture and noise in Hyperion image and finally leaves 134 bands and then it conducts absolute radiation value conversion, bad line repair, stripe removing, Smile effect removing and Flassh atmospheric correction of the above mentioned bands. The pixel gray values are converted to reflectance data (Tan *et al*., 2005). Secondly, it conducts radiometric calibration of ALI image, 6S atmospheric correction and geometric correction.

GS fusion effect comparison based on different first component simulation methods: It adopts GS1, GS2 and GS3 of three kinds of GS first component simulation

Table 1: Fusion result comparison of the 31st band in experiment area 1

	EGS	G	R(Hyp)	R(ALI)	NC	D	RMSE
Hyperion -1/31	-	4.0100	-	-	-	-	-
ALI-Pan	-	8.4106	-	-	-	-	-
GS1	14.3954	8.6451	0.9089	0.9863	39.3385	0.2793	50.7658
GS2	15.6527	9.0548	0.9385	0.9097	41.3251	0.2865	48.9623
GS3	14.2200	8.8643	0.9344	0.9621	40.5265	0.2746	50.5364

Table 2:Fusion result comparison of the 115th band in experiment area 2

	EGS	G	R(Hyp)	R(ALI)	NC	D	RMSE
Hyperion -2/115	-	4.7562	-	-	-	-	-
ALI-Pan	-	8.3423	-	-	-	-	-
GS1	13.2477	10.7678	0.9121	0.9733	31.7955	0.2723	28.9602
GS2	15.0965	14.0982	0.9433	0.9157	29.6316	0.2666	30.9378
GS3	14.7800	13.5423	0.9412	0.9601	30.5987	0.2677	30.5364

methods to conduct fusion experiment for the experiment area related images. As the three methods of GS1, GS2 and GS3 have higher and good fusion performance and the fusion image quality is generally higher and the visual effect is closer, thus it is not suitable for qualitative evaluation. The following will measure the above mentioned three kinds of methods' fusion effect through quantitative evaluation. It randomly selects the 31st band (Hyperion-1/31) of Hyperion image in experiment area 1 before fusion and the 115th band(Hyperion-2/115) of Hyperion image in experiment area 2 before fusion. Combined with the corresponding ALI panchromatic band (ALI-Pan) and fusion image, it respectively calculates the evaluation parameters of GS1, GS2 and GS3 fusion. The calculated results are as shown in the following Table 1 and 2.

In Table 1 and 2, R (Hyp) and R (ALI), respectively represents the spectral correlation coefficient and spatial correlation coefficient, namely, the correlation coefficient between fusion image and multispectral image and high spatial resolution image. Through the comprehensive analysis of fusion result of GS1, GS2 and GS3 of the three methods, GS1's R (ALI) value is the largest (namely the spatial information enhancing effect is the best) and GS1's R (Hyp) is the lowest(namely the spectral fidelity is the lowest). This is because spectral feature and GS inverse transformation adopting panchromatic band exist difference and the fusion image spectral feature exists a certain degree of distort. Contrast to GS1, GS2 has the highest spectral fidelity but the spatial information enhancing effect is the worst. The R(Hyp) and R(ALI) of GS3 method is between GS1 and GS2, which is closer to the maximum value. So GS3 fusion method can maintain higher spectral fidelity and have better spatial information enhancing effect, which is an ideal fusion method. Other evaluation parameter values (G, EGS, D, RMSE and NC) of GS3 are basically between GS1 and GS2. After fusion, three methods' G values are improved, namely, the clarity of the three methods of fusion image is improved.

To sum up, in the three fusion methods of GS1, GS2 and GS3, GS3 can obtain the best fusion effect, which is more suitable for Hyperion hyperspectral image and ALI panchromatic band fusion.

GS3 AND NON GS HYPERSPECTRAL IMAGE FUSION METHOD COMPARISON RESEARCH

Apart from GS transformation method, in the current remoting sensing field, other commonly used pixel level image fusion methods are IHS transformation, ratio transformation method (Brovey), weighted average method (WAM), Multiplicative Transformation Method (MPL), Main Component Analysis Method (PCA), Pyramid decomposition method (PD), Wavelet Transform Method (WLT), High Pass Filtering Method (HPF) and Smooth Regulating Filter (SFIM) , altogether 9 methods . Among them, IHS transform and Brovey transform fusion methods are only used for 3 bands' multispectral image and panchromatic image, which is not suitable for hyperspectral image. Pyramid decomposition fusion method can conduct better fusion calculation for different sensor images but because its layer decomposition amounts have correlation, leading the fusion effect to be not ideal. The high pass filtering fusion method adopts fixed size of filter, so it is hard to conduct arbitrary scale decomposition of the image data and the fusion image also includes larger noise. The research adopts 6 fusion methods of GS3, WAM, MPL, PCA, WLT and SFIM to conduct Hyperion hyperspectral image and ALI panchromatic band fusion experiment in experiment area 1 and 2, making evaluation of each method's fusion effect, respectively from the qualitative and quantitative aspects.

Qualitative evaluation of fusion effect: The images of two experimental areas before and after fusion are respectively as shown in Fig. 4 and 5. It, respectively compares the Hyperion hyperspectral image and ALI panchromatic image of the fusion image in the two experiment areas before and after fusion, finding that adopting GS3, WAM, PCA and SFIM fusion method can greatly improve the visual effect of image, making the information and spatial texture information of fusion image more full and clearer, which can better reflect the detailed features of image.

In the adopted 6 different fusion methods, GS3 fusion method obtains the best fusion effect and the whole visual effect is more full than the original image, the color difference of water and plant and other surface features is smaller and the texture information of roads and

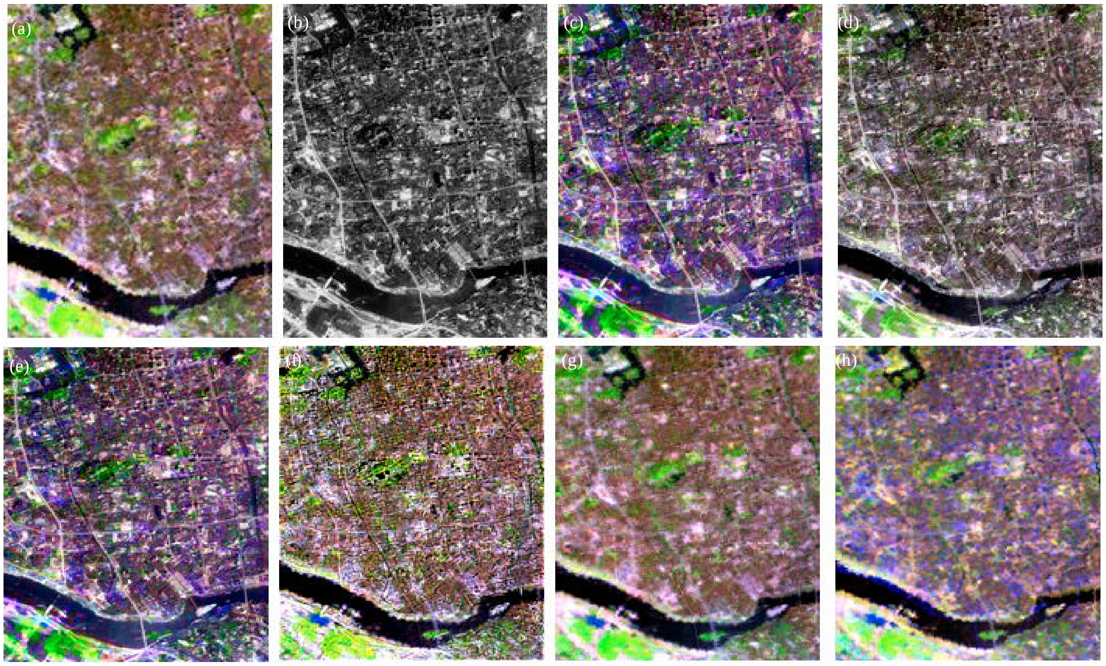

Fig. 4(ah): Fusion image of experiment area 1, (a)Hyperion, (b) ALI-Pan, (c) GS3, (d) WAM, (e) PCA, (f) SFIM, (g) WLP and (h) WLT

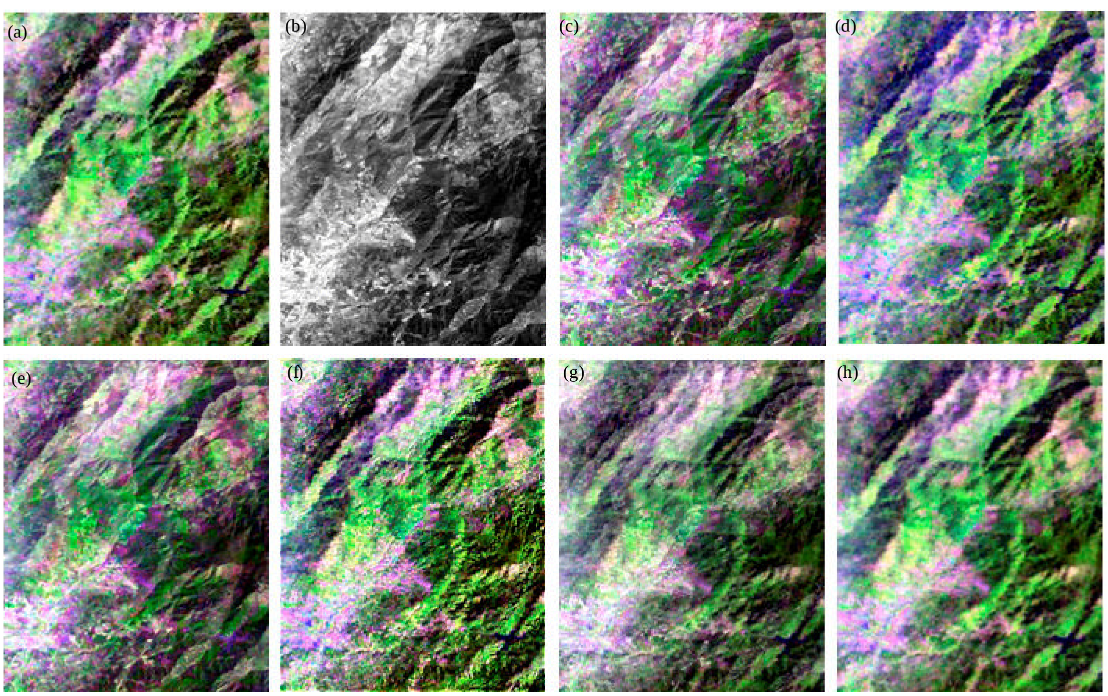

Fig. 5(a-h): Fusion image of experiment area 2, (a)Hyperion, (b) ALI-Pan, (c) GS3, (d) WAM, (e) PCA, (f) SFIM, (g) WLP and (h) WLT

Table 3: Fusion result comparison of the 15th band of experiment area 1

	EGS	G	R(Hyp)	R(ALI)	NC	D	RMSE
Hyperion -1/15	-	4.3685	-	-	-	-	-
ALI-Pan	-	8.5654	-	-	-	-	-
SFIM	15.4700	9.4701	0.9138	0.9403	42.2650	0.3211	55.1360
MLP	17.3600	8.0921	0.8478	0.8422	88.3571	0.3964	101.4659
WAM	14.6900	8.7201	0.9033	0.9394	41.7693	0.2974	53.8449
WLT	16.6900	8.4071	0.8519	0.8921	68.9380	0.3521	70.5164
PCA	16.2500	9.8351	0.9293	0.9424	42.5568	0.3133	56.4395
GS3	14.4252	10.6311	0.9283	0.9562	40.9651	0.2946	53.6452

Table 4: Fusion result comparison of the 90th band in experiment area 1

	EGS	G	R(Hyp)	R(ALI)	NC	D	RMSE
Hyperion -2/90	-	6.0100	-	-	-	-	-
ALI-Pan	-	10.9621	-	-	-	-	-
SFIM	15.8700	11.6542	0.9196	0.9517	38.5422	0.3145	31.6554
MLP	20.4600	9.0932	0.8578	0.8398	54.3452	0.4164	46.4659
WAM	14.8300	11.2201	0.9233	0.9425	31.5654	0.2844	33.8449
WLT	18.3100	9.9150	0. 8628	0.8968	43.4599	0.3343	36.5164
PCA	15.6500	13.5183	0.9283	0.9591	38.7743	0.2922	32.4395
GS3	14.7800	14.6632	0.9437	0.9528	30.8905	0.2788	31.0365

architectures is clearer but PCA fusion method is less clearer. SFIM fusion method makes image brighter and the surface feature edge is greatly strengthened. WAM fusion method makes image color basically unchanged and the surface feature edge is clearer. The fusion images of WLP and WLT method exist obvious edge fuzzy phenomenon, especially the former fuzzy degree is more obvious. In summary, the image by using GS3 method for fusion can maintain the original spectral information to the greatest degree and improve the spatial resolution at the same time.

Quantitative evaluation of fusion effect: It randomly selects the 15th band of Hyperion image (Hyperion-1/15) in experiment area 1 before fusion and the 90th band of Hyperion image (Hyperion-2/90) in experiment area 2 before fusion. Combined with the corresponding ALI panchromatic band (ALI-Pan) and fusion image, it respectively calculates the quantitative evaluation parameter values of experiment area 1 and 2 fusion images. The calculation results are as shown in the following Table 3 and 4.

In Table 3, GS3 fusion image's spectral correlation coefficient R (Hyp) is the largest and the spatial correlation coefficient R (ALI) is the second and in Table 4, the above two are in the opposite. In addition, GS3 fusion image's other evaluation parameters are the optimal. It shows that compared with other methods, GS3 transform fusion is an ideal hyperspectral and high spatial resolution remote sensing image's fusion method. The method has obvious advantage in maintaining the original image's spectral information and improving the clarity aspect, compared with other algorithms. PCA method fusion effect is secondary to GS3 method but better than SFIM method. WAM method fusion effect is secondary to SFIM but MLP and WLT method fusion effects are obviously poor (MLP is the worst).

From the above analysis, GS3 fusion method is an ideal hyperspectral and high spatial resolution remote sensing image fusion method, which has obvious advantage in maintaining original image's spectral information and improving its clarity aspect, compared with other 5 algorithms. This conclusion is basically consistent with the previous qualitative evaluation conclusion. The fusion image of the method has the strongest spectral information feature maintaining ability and the highest clarity, with the minimum spectral deviation degree of fusion image and original image and the highest fidelity, so as to be most beneficial to image classification and surface feature recognition.

CONCLUSION

The hyperspectral image fusion method based on Gram_Schmidt improved algorithm (GS3) can effectively improve the fusion effect of hyperspectral remote sensing image and high spatial resolution image and it can maintain the spectral feature and spatial texture feature of hyperspectral image at the same time, which has better fusion effect compared with other hyperspectral image fusion method. GS3 fusion method can effectively solve the problem of low spatial resolution in hyperspectral remote sensing image classification and it can reduce the adverse effect of mixed pixels to some extent, which makes hyperspectral resolution image and high spatial resolution image complement each other, so as to greatly improve the classification accuracy of hyperspectral image.

ACKNOWLEDGMENT

The authors would like to thank for the support of National natural science foundation of China (NO. 41201417) and the Science and Technology Project of Fujian Province Education Department of China (NO. JA13364).

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