AN AUTO-ADAPTIVE INFORMATION PRESERVATION FUSION METHOD FOR SAR AND MULTISPECRAL IMAGES

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ABSTRACT：

Due to the special imaging model of SAR, its image includes certain special information that unavailable in multispectral image, however, the interpretation of SAR image becomes more difficult than visible image. Therefore, the fusion of SAR image and multispectral image is primarily for the purpose of making better use of SAR image information. For this application, the auto-adaptive information preservation fusion method based on wavelet transform was proposed. It automatically adjusts weight coefficient according to the information capacity of SAR image and multispectral image, and then auto-adaptively adjusts fusion result, avoiding a single and ponderous fusion strategy for the whole image. Experiment results show that the novel method can better preserve SAR image texture and structure information, especially the unique information in SAR image, meanwhile, the novel method as well as better preserved spectral information with good results.

1. INTRODUCTION

The remote sensing images acquired by various single sensors have some limitation and differences in the respect of geometry, spectrum and spatial resolution. Therefore, it is necessary to fuse or synthesize the information contained in the images of multiple sensors, in order to enhance the distinguishing reliability and interpreting ability of the images (Li,2003), and prepare for the classification, target recognition and other more latter applications.

The traditional processing method is that fusing multispectral image of low spatial resolution and panchromatic image of high spatial resolution and gaining result image which not only owing higher spatial resolution in panchromatic image but also obtaining spectral information in multispectral image. As respect to application, the processing method might enhance the interpreting ability of original images. Nevertheless, different applications require the fused images not just eclectically contain the detail information in panchromatic image and spectral information in multispectral image. As for the application of feature extraction, mapping, the detail information of image is normally more important; while as for the application of classification, it is normally more important to focusing on the accuracy and integration of the spectral information (Deng,2005).

For the fusion of synthesize aperture radar (SAR) image and multispectral image, SAR image is regarded as main body to contain the detail information better, and the multispectral image is used to supply additional spectral information. As the imaging mode of SAR is active in microwave band, SAR can penetrate clouds, rain and snow, and bear the ability of round-the-clock working and in some sense penetrating earth's surface (Woodhouse, 2004). Therefore, SAR sensor might acquire information that unavailable for visible or infrared sensor. However, as the special imaging way SAR has, the interpretation of SAR images is more difficult than that of the visible ones, it is necessary to fuse SAR image and multispectral image, in order to better utilize the special information SAR image contained.

The traditional fusion methods including Intensity-Hue-Saturation (IHS) transform, Principle Component Analysis (PCA), Wavelet Transform and High Pass Filter (HPF), etc. And more and more advanced methods based on the traditional fusion methods have proposed (Li,1994). Most of these methods focus on preserving spectral information or eclectically preserving information between spatial detail one and spectral one, which resulting the fused image usually only advance the visible effect. But scarce methods regard panchromatic image as main body, aiming to maintaining as much as detail information.

In this paper, from the aspect of application-oriented, we proposed a novel fusion method to synthesize SAR image and multispectral image. This novel method is based on wavelet transform, which we called auto-adaptive information preservation fusion method. It not only better preserves spectral information in multispectral image, but also, more importantly, preserves special detail information in SAR image.

2. THE TRADITIONAL FUSION METHODS BASED ON WAVELET TRANSFORM

An image can gain (3*J*+1) components by *J*-level two-dimension discrete wavelet transform, one of which is low-frequent approximate component, noted as L^j, owing major energy of original image, the other 3*J* ones, noted as H_1^j, H_2^j and H_3^j respectively, are high-frequent detail

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components concentrating detail information of original image. We note original image *f(x,y)* as L^0, and the 3-level two-dimension discrete wavelet decomposition of image is shown as Figure.1.

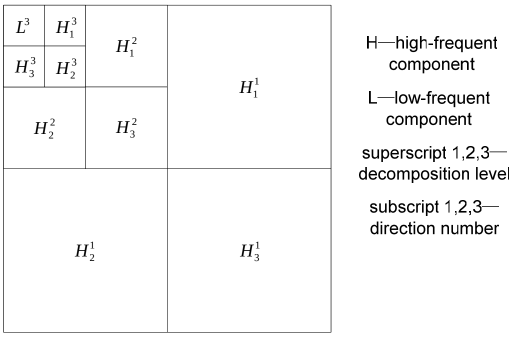


Figure. 1 The 3-level two-dimension discrete wavelet destruction of image

In traditional fusion method based on wavelet transform, detail component of multispectral image is substituted by detail component of panchromatic image in frequent domain, and then fused image is obtained by reconstruction of wavelet coefficients of multispectral image. Let *P*, *X* and *F* are panchromatic image, multispectral image, and fused image, respectively. The process of fusion based on wavelet transform is as follows:

1. After the strictly registration and other pre-processing of *P* and *X* images, the *J*-level two dimension discrete wavelet decomposition are done for the two images respectively, and the pyramid images of *P* and *X* images, noted as P^{pym} and X^{pym} respectively, are obtained, containing the corresponding low-frequent approximate components and high-frequent detail components.

2. The detail component of X^{pym} is substituted by that of P^{pym}, and the low-frequent approximate component of X^{pym} is preserved, then the fused pyramid image F^{pym} is obtained. Therefore, F^{pym} is consists of the detail components of P^{pym} and the approximate component of X^{pym}.

3. The fused image *F* is obtained by reconstructing and reverse transforming the fused pyramid image F^{pym}.

In traditional fusion methods based on wavelet transform, due to the directly abnegation of low-frequent approximate component of panchromatic image, the detail information of panchromatic image lose in some sense. Fortunately, many advanced methods have proposed (Li,1994), but they nearly preserves information of original images in the application-oriented aspect. Consequently, traditional fusion methods based on wavelet transform still eclectically preserve spatial detail information and spectral information.

3. AUTO-ADAPTIVE INFORMATION PRESERVATION FUSION METHOD BASED ON WAVELET TRANSFORM

The idea of the novel fusion method regards SAR image as main body, aiming to preserving information of SAR image better, and performing the fusion according to auto-adaptive information preservation. The algorithm is as follows:

1. A window of $n \times n$,（n=3,5,…,N) is defined. Let *S* is SAR image, *X* is multispectral image, and k=1,2,…,K represents the band sequence of multispectral image. The entropies of *S* and each band of X_k in the window are calculated.

$$H_s(x,y) = -\sum_{i=0}^{I} P_{si} \ln P_{si} \tag{1}$$

$$H_k(x,y) = -\sum_{i=0}^{I} P_{ki} \ln P_{ki} \tag{2}$$

where, i = 0,1,…,I is digital number (DN)，(x, y) is position of the central-pixel in the window, P_{si} and P_{ki} are ratios of the *i* pixel number to the total pixel number in the window for SAR image and multispectral image, respectively.

2. The discrepancy of information capacity between SAR image and the *k*th band of multispectral image is expressed by the weight $W_k(x,y)$:

$$W_k(x,y) = H_s(x,y) / H_k(x,y) \tag{3}$$

3. The window is employed to move and perform the same operation of 1-2 steps, and the circulation does not cease until the entire image is covered at all. And a new weight image of the *k*th band W_k is accomplished. Hence, all of *K* weight images corresponding to *K* bands of multispectral image are gained.

4. The normalization of weight images is done to limit $W_k(x,y)$ between 0 and 1:

$$W_k^{normal}(x,y) = \frac{W_k(x,y) - W_{k\min}}{W_{k\max} - W_{k\min}} \tag{4}$$

where, $W_k^{normal}(x,y)$ is the normalization of $W_k(x,y)$, $W_{k\max}$ and $W_{k\min}$ are the maximum and minimum of $W_k(x,y)$, respectively.

5. The *J*-level two dimension discrete wavelet decomposition

are done for SAR image *S*, multispectral image X_k and normalized weight image W_k^{normal}, and pyramid image S^{pym}, X_k^{pym} and W_k^{pym}, respectively, are obtained.

6. In wavelet domain, pyramid images S^{pym} and X_k^{pym} are fused according to the formula below, and fused pyramid image F_k^{pym} in wavelet domain is obtained.

$$F_k^{pym}(2^j,x,y)=\frac{S^{pym}(2^j,x,y)+W_k^{pym}(2^j,x,y)\times X_k^{pym}(2^j,x,y)}{1+W_k^{pym}(2^j,x,y)} \qquad (5)$$

where, j=1,2,…,J is pyramid level, 2^{-j} is resolution, and $F_k^{pym}(2^j,x,y)$ is the value of pyramid image on j-level at (x, y) position.

7. By reconstructing pyramid image F_k^{pym}, fused image of the kth band F_k is ultimately obtained. Hence, the whole fusion image is gained.

As we can see from the algorithm, along with moving of the window, the fusion image might auto-adaptively fuse information of the two images according to the information capacities of SAR image and multispectral image, more sufficiently considering local features of images, but not perform the whole image with a single and ponderous way.

4. EXPERIMENT AND RESULTS ANALYSIS

For the sake of validating the effectiveness of the algorithm, we employed a RADARSAT fine model image, with 10m*10m resolution, as the original SAR image, and a fused SPOT-5 image, with 2.5m*2.5m resolution, as the original multispectral image. The fused SPOT-5 image is synthesized by the SPOT-5 multispectral bands with 10m*10m resolution and the SPOT-5 panchromatic band with 2.5m*2.5m resolution. As we all known, the image fusion usually occurs with a high resolution panchromatic image and a low resolution multispectral image, yet it is opposite in this paper. Both of these strategies are based on the fusion destination, in the usual situation, we want to acquire an image holding high spatial resolution and fine spectral information; while in the application-oriented situation we assumed, we would like to gain an image with sufficient spectral information and as more SAR information as possible. So the original images are just designed for this purpose.

The comparison is done between the novel fusion method and other traditional fusion methods, such as Brovey (Zhang,2006), triangle IHS (Wang,2000), PCA (Jia,1998), Gram-Schmidt (Li,2004) and wavelet transform method in article (Li,1994). With respect to the fusion method based on wavelet transform in this paper, both the normal wavelet transform method and the novel method adopted the sym4 wavelet base. The window size in the novel method is 7*7 pixels. The image size is 1024*1024 pixels.

The original and result images are shown in Figure.2, where, Figure2(a) is RADARSAT image, Figure2(b) is multispectral image, Figure2(c)-(h) are the fused image of Brovey, triangle IHS, PCA , Gram-Schmidt, normal wavelet transform, and the novel method, respectively.

(a)SAR image

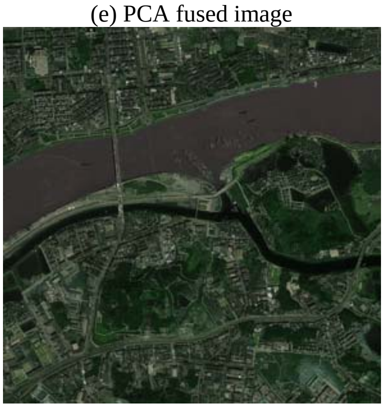
(b) multispectral image

(c) Brovey fused image

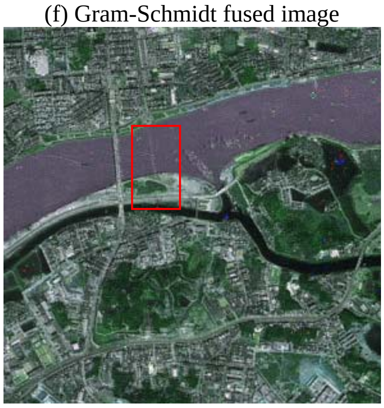
(d) triangle IHS fused image

(e) PCA fused image

(f) Gram-Schmidt fused image



(g) normal wavelet transform fused image



(h) the novel method fused image

Figure. 2 SAR image, multispectral image, and the result images of different fusion methods

4.1 Subjective Qualitative Analysis and Comparison

As for visual effect, the normal wavelet transform and the novel method have the advantages of preserving spectral information over the other methods. Brovey is the simplest, but the fusion effect is the worst. Triangle IHS, PCA and Gram-Schmidt keep too much information of SAR image, but lose most of spectral information. Besides, the spectral information distributes unevenly, resulting the distortion of the image hue. In so far as the normal wavelet transform and the novel method, the former is not as good as the latter in preserving information of the SAR image, and also with hue distortion from the original multispectral image; while the novel method not only preserves spectral information better, but also auto-adaptively keeps the texture feature of the SAR image, so that the fused image is smooth and natural in visual. Furthermore, the novel method has the advantage of preserving information of SAR image. For instance, the representative object circled by the red rectangle in Figure1(a) is the special information in the SAR image, which preserved fully in the novel method, while relatively poor for PCA or normal wavelet transform method. Comprehensively, concerning visual effect, the novel method is relatively the best fusion method.

4.2 Objective Quantitative Analysis and Comparison

Certain objective quantitative analyzing indexes are utilized to compare the fusion effects and information preservation abilities of different fusion methods adopted in this paper. We employed mean, standard deviation, entropy, correlation coefficient, average gradient and spectral distortion to reflect image luminance, spatial detail information preservation, and spectral information preservation (Luclen, 1997).

1. Mean and Standard Deviation (S. D.):

In statistics, mean $\hat{\mu}$ and standard deviation $\hat{\sigma}$ are defined:

$$\hat{\mu} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{6}$$

$$\hat{\sigma}^2 = \frac{1}{n-1}\sum_{i=1}^{n} (x_i - \hat{\mu})^2 \tag{7}$$

where, n is the sample size, x_i is the value of the ith sample.

Here, mean is the average gray value of all the pixels in the image, and for the human visual system, it is the average luminance. So if the mean is moderate, the visual effect is fine. Standard deviation represents the discrete degree of the pixel value relative to the mean. The larger the deviation is, the more dispersedly the gray grades distribute, and if the probability of each gray grade equals, the information capacity is the maximum.

2. Entropy:

The entropy of the image is an important index to weigh the information capacity, according to the Shannon's information theory principle, the definition of entropy is:

$$H = -\sum_{i=1}^{m} P_i \ln P_i \qquad (8)$$

where, P_i is the ratio of the i pixel number to the total pixel number in the image, m is the number of grades.

Since the entropy represents the information capacity, the larger the entropy is, the more the image contains information. Seen from formula (8), we know that the maximum value of H occurs if and only if each P_i is equal. It means that the information capacity tends to be the maximum if each gray grade has almost the same account pixels. By comparison of the entropies of different images, we can judge the ability of expressing detail information.

3. Correlation Coefficient (C. C.)

The correlation coefficient between the original image and the fused image shows the similarity in small size structures between the original and the fused images. It should be as close as possible to 1 (Luclen, 1997). The correlation coefficient ρ is:

$$\rho = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(M(i,j)-\overline{M}(i,j))(F(i,j)-\overline{F}(i,j))}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(M(i,j)-\overline{M}(i,j))^2 \sum_{i=1}^{M}\sum_{j=1}^{N}(F(i,j)-\overline{F}(i,j))^2}} \qquad (9)$$

where, $M(i, j)$, $F(i, j)$ are the pixel value of original image and fused image in certain component, respectively. Correspondingly, $\overline{M}(i, j)$ and $\overline{F}(i, j)$ are the means. M and N are the weight and height of the image.

4. Average Gradient (A. G.)

Average gradient is able to accurately reflect the fine contrast of the image. Generally, the larger the average gradient is, the clearer the image is.

$$\nabla \bar{G} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\sqrt{\Delta xf^2(x,y)+\Delta yf^2(x,y)} \qquad (10)$$

where, $\Delta xf(x, y)$ and $\Delta yf(x, y)$ are the difference of $f(x, y)$ at x and y direction in certain component, respectively.

5. Average Spectral Distortion (A. D.)

The definition of the spectral distortion in the kth component is:

$$D^k = \frac{1}{n}\sum_i\sum_j \left|V_{i,j}^k - V_{i,j}'^k\right| \qquad (11)$$

where, $V_{i,j}^k$ and $V_{i,j}'^k$ are, respectively, the gray values of multispectral image and fused image in the kth component at position (i,j). As the spectral effect is expressed by the synthesized of the multiple bands, we employed the average spectral distortion, noted as D, to illustrate it. The greater the D is, the larger the distortion is.

Image	band	Mean	S.D.	Entropy	C.C with multi-spectral	C.C. with SAR	A.G.	A. D.
Multispectral	1	89.3915	2699.9938	7.2407	1.0000	—	16.1554	—
	2	100.7079	2370.8928	7.2342	1.0000	—	16.1896	—
	3	76.6344	2438.7121	7.0459	1.0000	—	15.9443	—
SAR	-	57.7986	2438.6782	7.0837	—	1.0000	11.8878	—
Brovey	1	36.2861	3745.5817	6.0136	0.1195	0.7344	20.4025	
	2	43.7587	4371.4152	6.3431	0.1315	0.6349	28.0559	212.7874
	3	39.4694	4757.6124	5.9325	0.1931	0.5908	29.3560	
Triangle IHS	1	55.3576	2411.2494	7.0468	0.1136	0.9457	13.4192	
	2	66.3127	2635.3794	7.3110	-0.0064	0.9334	15.6292	165.2970
	3	47.5083	2397.7407	6.7985	0.1503	0.8508	14.3046	
PCA	1	30.6315	106.7828	4.8998	0.0962	0.6671	2.0525	
	2	29.9306	175.8581	5.5172	0.2041	0.5935	2.1249	180.1813
	3	29.6898	110.6867	4.9486	0.1016	0.6612	2.1421	
Gram-Schmidt	1	20.7771	172.5953	5.4618	0.1937	0.8778	3.0947	
	2	40.2084	361.7482	6.2062	0.1502	0.8136	3.8246	195.1719
	3	10.9059	146.2115	4.8158	0.1034	0.9003	2.8324	
Normal wavelet transform	1	40.0525	482.7768	6.3879	0.9572	0.2869	6.7017	
	2	54.6524	649.9612	6.6190	0.9684	0.2852	8.3276	127.3534
	3	42.6195	663.5351	6.5742	0.9690	0.2548	8.2042	
The novel method	1	83.3250	1859.9954	7.3748	0.8014	0.3683	12.1231	65.1349
	2	92.1778	1652.6537	7.3236	0.7828	0.4196	11.7862	

	3	73.0405	1682.2747	7.2781	0.7835	0.3869	11.8644	

Table 1. The quantitative analysis results of different fusion methods

With respect to image luminance, the mean of the novel method range between that of the multispectral image and the SAR image, while the means of the other methods are generally low. This shows that the novel method well reflects the original image luminance, which coincides with the subjective analysis result.

In the aspect of spatial detail information preservation, 1) Standard deviation: the triangle IHS result has the closest standard deviation to the original image, and in the next place the novel method; while the Brovey method exorbitantly stretched the gray gradient, resulting the image distortion; the standard deviations of PCA result, Gram-Schmidt result and normal wavelet transform result are comparatively smaller, as the distributions of their gray gradient are too concentrated. 2) Entropy: the entropy of the novel method is larger than that of any other method, and it is only the novel method result that has the larger entropy than the original image, which shows that the novel method has the advantage of preserving information over other methods. 3) Average gradient: the average gradients of the PCA result, Gram-Schmidt result and normal wavelet transform result are comparatively smaller, which shows that these methods are less able to reflect the small detail information; Although the average gradient of Brovey result is the largest, it is larger than that of both the multispectral image and the SAR image, not truly reflecting the detail information; The average gradients of the novel method result and triangle IHS result are between that of the multispectral image and the SAR image, however, the average gradient of the novel method result is more closed to that of the SAR image, which means that the novel method excels triangle IHS in preserving detail information of SAR image, the very intention we desired.

In the aspect of spectral information preservation, 1) Correlation coefficient: the correlation coefficients of Brovey result, triangle IHS result, PCA result with SAR image are larger than the ones with multispectral image , respectively, while the situations of normal wavelet transform and the novel method are reverse. Other than Brovey method, triangle IHS and PCA are Component Substituting methods (Pradhan,2005), therefore the correlation coefficients of their result images with SAR image are naturally larger, so it has no comparability with the novel method. As for the novel method and normal wavelet transform, the former has a larger correlation coefficient with SAR image than the latter, meaning that the novel method is the better one in preserving information of SAR image. 2) Spectral distortion: the average spectral distortion of the novel method result is 65.13, the smallest one, while that of other method results are over 120, meaning the novel method lost the least spectral information.

Therefore, synthesized the subject qualitative and objective quantitative analysis, compare with the traditional methods concerned in this paper, the novel method not only has obvious advantage in preserving detail information of SAR image, but also is better in spectral information preservation and distribution.

5. CONCLUSIONS

From the application-oriented aspect, this paper proposed auto-adaptive information preservation fusion method based on wavelet transform, aiming at better utilizing the information of SAR image in latter application. It sufficiently considers the local feature of the image, auto-adaptive fused SAR image and multispectral image according to the local information capacity, but not single and ponderous fused regulation for the whole image.

The experimental result shows that the novel method is better than the traditional methods adopted in this paper. The novel method not only better preserves spectral information in multispectral image, but also better preserves detail information in SAR image. Especially, the special SAR information is contained in the novel method fused image. However, the novel method still has room for improvement.

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REFERENCES

References from Journals:

Deng L., Chen Y., Li J., et al.,2005. Controllable remote sensing image fusion method based on transform. Journal Infrared Millimeter and Waves. 24(01), pp. 34-38.

Jia Y.,1998. Fusion of Landsat TM and SAR Images Based on Principal Component Analysis. Remote Sensing Technology and Application. 13(01), pp. 46-49.

Li C., Liu L., Wang J., et al.,2004. Comparison of Two Methods of Fusing Remote Sensing Images with Fidelity of Spectral Information. Journal of Image and Graphics. 9(11), pp. 1376-1385.

Luclen W., Thlerry R. M. M.,1997. Fusion of Satellite Images of different spatial resolutions: assessing the quality of resulting images[J]. Photogrammetric Engineering & Remote Sensing. 63(6), pp. 691-699.

Wang R., Qi M., Wang H.,2000. Comparative Study on the Method of IHS Transformation for Image Fusion. Journal of The Pla Institute of Surveying and Mapping. 17(04), pp. 269-272.

Zhang Y., Wu Q.,2006. Information Influence on QuickBird Images by Brovey Fusion and Wavelet Fusion. Remote Sensing Technology and Application. 21 (01), pp. 67-70.

References from Books:

Li B., Luo J.,2003. *Wavelet analysis and application*. Beijing: Publishing House of Electronics Industry.

Li H., Manjunath B. S., Mitra S. K.,1994. *Multisensor Image Fusion Using the Wavelet Transform.*

Woodhouse I. H.,2004. *Introduction to microwave remote sensing*. Taylor & Francis CRC Press.

References from Other Literature:

Pradhan P.,2005. Multiresolution Based, Multisensor, Multispectral Image Fusion. Mississippi State, USA.