A COMPARATIVE STUDY ON THE FUSION RESULTS OF SENTINEL-1 / GF-3 SAR IMAGE AND GF-1 OPTICAL IMAGE

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ABSTRACT: The fusion of SAR image and optical image can complement each other and improve the ability of image interpretation. In this paper, the fusion results of Sentinel-1 and GF-3 SAR images fused with moderate-resolution GF-1 images respectively are compared and analyzed by using Brovey, Gram-Schmidt Pan Sharpening, PCA and wavelet transform methods. In the meanwhile, the indexes of mean, standard deviation, information entropy, average gradient and correlation coefficients are constructed to evaluate the fusion results. The results show that the fusion results of Sentinel-1 and GF-1 using different fusion methods are better than the results of GF-3 and GF-1. Different fusion methods adopted have different fusion results of Sentinel-1 and GF-1 images. For image information, texture and spectral fidelity, the fusion results adopting PCA and Gram-Schmidt Pan Sharpening methods are optimal, the fusion result by using wavelet transform method contains more plenty of image spectral information, and the fusion result obtained by Brovey method presents significant color distortion. However, the fusion results of GF-3 with GF-1 are not satisfied for the heavy speckle noises of GF-3.

1 INTRODUCTION

Synthetic aperture radar (SAR) has the ability to collect data throughout all day time and all weather conditions，and it has some penetrability，which can detect geometric shapes and structures such as topographic features, thickness and surface roughness(Gormus et al., 2010). But SAR images can’t obtain the spectral attributes of the detection targets and be quite different with visual impression. Because of the speckle noises in the image, it is difficult to detect and identify the target by using only SAR image. Multispectral images can provide spectral information of features. Moderate- resolution optical images are readily available and have large swath width. But optical images are easily interfered with cloudy weathers, optical conditions and have no penetrability. Then we combine SAR and Moderate- resolution optical images, make full use of their complementarity. It can provide more valuable information for the following image processing tasks such as segmentation, identification and change detection.

For SAR and optical image fusion, Cao Y. X. et al. analyzed and evaluated the advantage of three fusion methods for the detection of ground object based on high resolution airborne SAR and SPOT5 multi-spectrum images. The three methods are PCA, HIS and multiplicative compound transformation (Cao et al., 2007). Han N.L et al. used wavelet transform based on A'Trous and Mallat algorithm to fuse ERS-2 SAR and TM images respectively. By comparison, they found the results based on A'Trous wavelet transform optimal, The fused images have improved greatly in spectrum and texture (Han et al., 2010). Wan J. H. et al. proposed a new method based on PCA and HSV color spatial conversion, which can effectively use texture information in fully polarimetric SAR data to improve image interpretation ability (Wan et al., 2017). Ahmed T. et al. used genetic algorithm to fuse MODIS and ALOS PALSAR images in hot spots detection, which can effectively improve identification rate of the hot spots (Ahmed et al., 2016).

In conclusion, different fusion methods have different fusion results in different SAR, optical satellite data and different purposes of application. The appropriate fusion method can enhance the effect of image application, otherwise it can cause spectral deformation or loss of information. For the moment there are few reports on the Sentinel-1 and GF-3 SAR fusion method and effect evaluation. This paper adopts some fusion methods to process Sentinel-1 and GF-3 data. Then it comprehensively analyzes visual effects and various quantitative evaluation indexes. At last, it compares the effect of different fusion methods which can provide reference for the two kinds of SAR data fusion.

2 DATA AND PREPROCESSING

2.1 Data

(1) Sentinel-1 SAR Data: Sentinel-1 constellation is the first mission of the Copernican project in Europe, which consist of two satellites, A and B. The revisit period of single satellites is 12 days. After two satellites networks, the

revisiting cycle is shortened to 6 days. Sentinel-1 equipped with C-band SAR sensor which adopt 4 imaging modes such as: Stripmap(SM), Interferometric Wide swath(IW), Extra-Wide swath(EW) and Wave(WV).
In this paper, the imaging mode of the Sentinel-1A is IW. The swath width of the image is 250km. Image resolution is 5m*20m, which adopt VH polarization mode. The acquisition time is Jun 1st, 2016.

(2) GF-3 SAR Data: GF-3 is the first of Chinese C-band multi-polarization high resolution SAR satellite, which successfully launched on August 10th, 2016. GF-3 satellite incident angle range is about 20°to 50°that currently has the most imaging mode in the world such as Stripmap, Spotlight and Scan. The satellite's acquisition of remote sensing images in different application modes can be realized in limited time. The resolution of the image is from 1~500m, and the swath width is from 10~650km.
GF-3 data adopted in this paper is Fine Stripe mode, its resolution is 5*5m, the swath width is 50*50km. Image adopts VH polarization mode. The acquisition time is October 2nd, 2016.

(3) GF-1 Optical Data: The GF-1 satellite was Chinese first self-developed high-resolution satellite, which was successfully launched in April 2013. The satellite carries a 2m resolution full-color, 8m resolution multispectral CCD camera and 16m resolution multispectral CCD camera. The 16m resolution CCD multispectral data is consisted of 4 cameras images and its swath width is larger than 800km.
GF-1 data adopted in this paper is a 16m resolution multi-spectral image acquired in WFV1 sensor on August 26th, 2016.

2.2 Preprocessing

Different kinds of SAR data adopt different processing methods. In the experiment, the mainly processing to SAR data is magnitude to intensity transform and geocoding. The mainly processing to GF-1 image is orthographic calibration, radiation calibration, atmospheric correction, etc. In order to ensure the image fusion effect, it is necessary to co-register the Sentinel-1, GF-3 with GF-1 images respectively and ensure that the coregistration error is less than 0.5 pixel. The detailed preprocessing procedure is shown such as Figure 1.

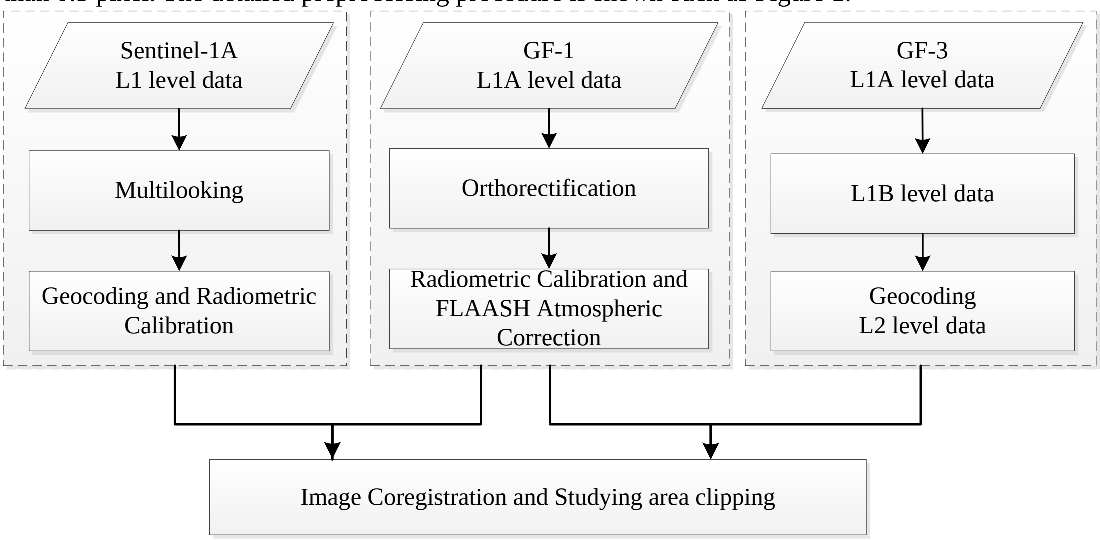


Figure 1 Preprocessing Procedure

3 FUSION IMAGE AND EFFECT EVALUATION METHODS

3.1 Fusion Image

(1) Principal component analysis(PCA): The method is a multi-image orthogonal linear transformation fusion method based on statistical feature (Chavez, 1992). The method transforms the multi-spectral image into the principal component. It assumes that the first principal component of the transformation contains all the same spatial information as the full color image. Then the high resolution fusion image is obtained through the principal component inversion (Meng et al., 2016).

(2) Brovey: Brovey is color standard transform fusion. The method use all bands in RGB image multiply by the ratio between high resolution image with RGB bands. Then the high resolution multispectral image is obtained by using the nearest neighbor interpolation, bilinear interpolation or cubic convolution interpolation to resample the three bands to high resolution pixel (Zhang et al., 2006; Xu and Fang, 2014).

(3) Gram-Schmidt Pan Sharpening (GS): First the multi-spectral image is transformed by GS. Then replace first component with full-color band. Obtain the fusion images by inverse transformation (Laben et al., 1998). The fusion method based on GS transformation has no band limit that can avoid information focusing on the first principal component. The method has high degree of spectral information retention.

(4) Wavelet: Wavelet transform is a transformation method between space domain and frequency domain. The frequency characteristics of image after wavelet decomposition are effectively separated. The low frequency part represents the overall visual information of the image and the high frequency part represents the images detail characteristics. Using high frequency component of high resolution image and the corresponding low frequency part of multispectral image for wavelet recombination can acquire fusion image. Because of wavelet fusion method keeping high frequency component of high-resolution image, the overall fusion effect is better. The basic idea of wavelet transform fusion is increasing the revolution of multispectral image and keeping the spectral information of multispectral image at the same time (Jim, 1996; Li et al., 1999).

3.2 Image Fusion Evaluation

The effect of images fusion can be evaluated by qualitative and quantitative methods. The qualitative method is mainly to evaluate the visual effect of the images through the clarity of the fusion images and the degree of spectral retention. And quantitative evaluation can evaluate the fusion effect of images quantitatively. The paper quantitatively evaluates the fusion images based on the mean, standard deviation, information entropy, average gradient and correlation coefficient index.

(1) Mean: It is the average brightness of the image reflected by average gray value of the pixel. The smaller change of pixel gray value of the corresponding band of images before and after fusing, the better spectrum is maintained. The calculation formula is as follows:

$$\bar{Z} = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N} Z(i,j) \tag{1}$$

where, M and N are rows and columns of images, and $Z(i，j)$ is the gray value of pixel.

(2) Standard Deviation: It reflects the dispersion of grayscale relative to mean gray value. In some ways, the standard deviation can also be used to evaluate the size of the image contrast. If standard deviation is large, it reflects that the image gray-scale distribution is discrete, the image contract is greater, and more information can be obtained. On the contrary, the small standard deviation reflects that image contract is small, the tone is uniform, and there is not much information in the image.

$$\sigma = \sqrt{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(Z(i,j) - \bar{Z})^2} \tag{2}$$

where, M and N are rows and columns of the image, $Z(i，j)$ is the gray value of pixel, and $\bar{Z}$ is the average value over all pixels in the image.

(3) Information Entropy: It is the index of the quantity of information and the richness of the images. The larger the entropy value is, the more information the fusion images contain, and the better the fusion effect is. The calculation formula is as follows:

$$E = -\sum_{i=0}^{l} P_i \log_2 P_i \tag{3}$$

where, P_i is frequency of occurrence of the NO.i grayscale.

(4) Average Gradient: It can be sensitive to reflect the image's expression ability of small details. It not only can evaluate the clarity of the image, but also reflect small detail contract and the small change characteristics of texture in the image. The calculation formula is as follows:

$$\bar{G} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \sqrt{\frac{1}{2}\left[\left(\frac{\partial Z(i,j)}{\partial x_i}\right)^2 + \left(\frac{\partial Z(i,j)}{\partial y_i}\right)^2\right]} \tag{4}$$

where, M and N are rows and columns of the image; $Z(i，j)$ is the gray value of pixel.

(5) Correlation Coefficient: It reflects the correlation degree of spectral signatures of the two images before and after fusing. The degree of spectral change can be reflected by comparison of images correlation coefficients before and after fusing. The calculation formula is as follows:

$$\rho = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left[F(i,j)-\bar{F}\right]\left[A(i,j)-\bar{A}\right]}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\left[F(i,j)-\bar{F}\right]^2\left[A(i,j)-\bar{A}\right]^2}} \tag{5}$$

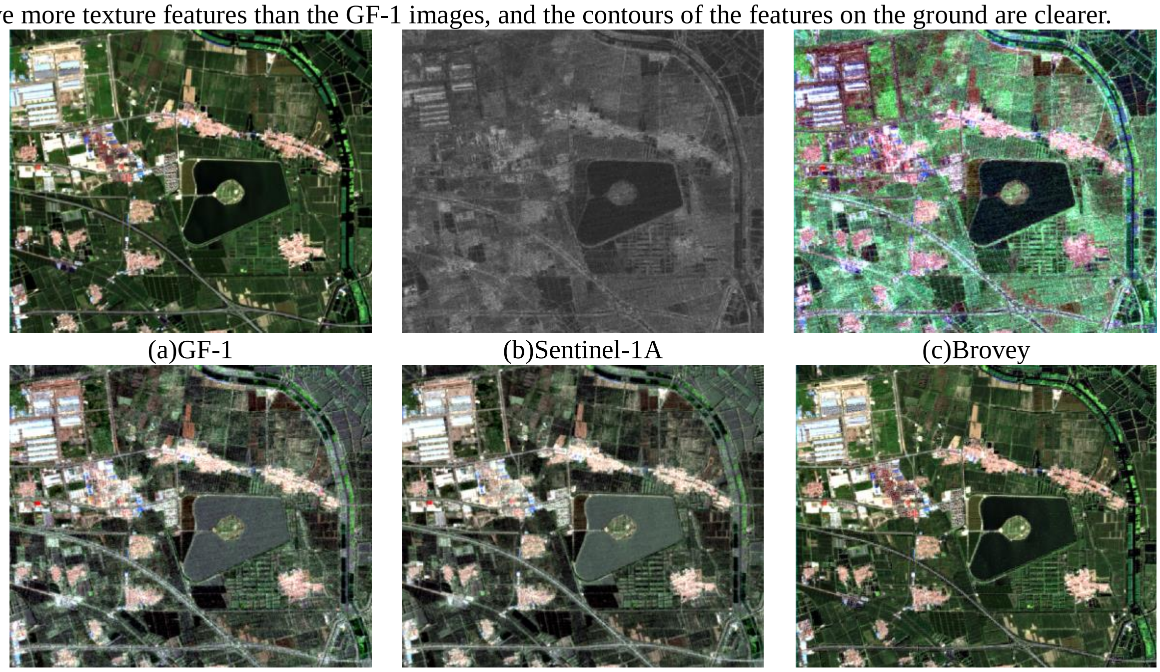
where, $A(i，j)$ is the gray value of the image before fusing; $\bar{A}$ is the mean value of gray value of image before fusing; $F(i，j)$ is the gray value of the image after fusing; $\bar{F}$ is the mean value of gray value of image after fusing.

4 CONCLUSION AND ANALYSIS

4.1 Qualitative Evaluation

In the experimentation, the ground features mainly include water, buildings, roads, vegetation etc. Different fusion methods are used to fuse Sentinel-1A, GF-3 with GF-1 images respectively. The results display as shown in Figure 2 and 3.

Comparing the color information of the before and after fusing images of Sentinel-1A with GF-1, we get some conclusions as follow: The color distortion of the fusion images obtained by Brovey method is obvious. The color of vegetation differs greatly from the original image. The small area of the river is light blue, which is different from the original image. But the large areas in the lack are black, which are consistent with the original image. The fusion results obtained by using method of Wavelet are closest to GF-1 in color, followed by PCA and GS. However, the water in the fusion images obtained by the latter two methods is deep green, and the distortion is more obvious than the black water in the GF-1 image. In addition, the fusion images obtained by the methods of GS and PCA have more texture features than the GF-1 images, and the contours of the features on the ground are clearer.

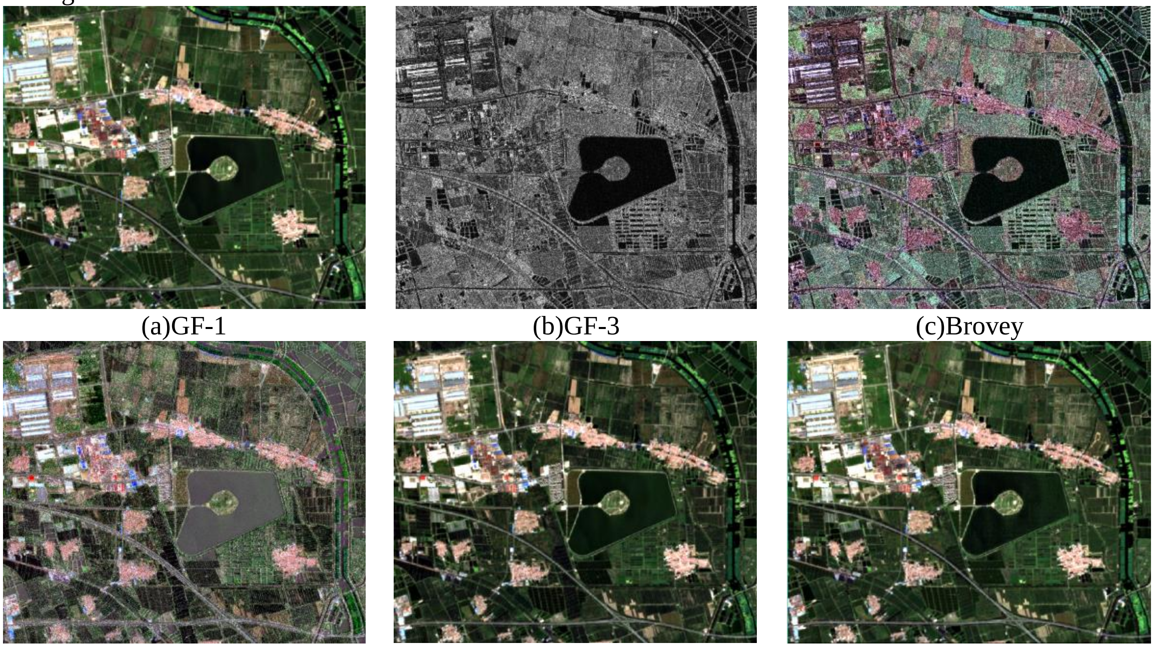


(a)GF-1 (b)Sentinel-1A (c)Brovey

(d)GS (e)PCA (f)Wavelet

Figure 2 Fusion of Sentine-lA with GF-1

Comparing the images that are before and after the fusing of GF-3 with GF-1, we get some conclusions as following: In the term of image color, the color distortion of the fusion images obtained by Brovey method is the most obvious. The spectral information of the images obtained by the methods of Wavelet and PCA preserved is the best, that obtained by the method of GS is the secondly. The water in the fusion images obtained by the methods of Wavelet and PCA is deep green, but the large water body in the fusion images obtained by the method of GS is deep gray which is different from the black water body in GF-1 images. In addition, comparing with GF-1 images, the color of bare soil in the fusion images obtained by the method of GS is deeper, and the fusion images have more texture information which can identify the detailed boundary feature information of the water body and the outlines of building.



(a)GF-1 (b)GF-3 (c)Brovey

(d)GS (e)PCA (f)Wavelet

Figure 3 Fusion of GF-3 with GF-1

4.2 Quantitative Evaluation

After visual qualitative evaluation, the mean, standard deviation, information entropy, average gradient and correlation coefficient are selected to evaluate the quality of fusion images. The result of quantitative evaluation of fusion images displays as shown in Table 1 and 2.

Table 1 Quantitative Evaluation of Fusion of Sentinel-1A and GF-1

image	band	mean	Standard deviation	Information entropy	Average gradient	Correlation coefficient
GF-1	R	671.87	421.29	10.19	62.58	/
	G	804.89	351.44	10.15	67.73	/
	B	598.54	343.77	9.69	57.48	/
Brovey	R	24.68	8.56	4.99	2.00	0.60
	G	31.21	7.67	4.95	2.40	0.18
	B	22.45	6.54	4.62	1.80	0.46
GS	R	621.24	396.92	10.47	80.29	0.79
	G	751.85	312.75	10.20	76.70	0.65
	B	553.30	329.92	10.19	72.92	0.75
PCA	R	592.54	488.45	10.71	86.03	0.86
	G	715.68	414.74	10.56	85.85	0.75
	B	527.99	410.21	10.43	78.10	0.85
Wavelet	R	669.59	422.70	10.30	78.65	0.98
	G	802.32	353.97	10.23	83.19	0.96
	B	596.51	345.61	9.87	71.39	0.97

Analyzing the 5 indicators of the fusion images of Sentinel-1A with GF-1 in Table 1, we can get some conclusions as follow: in terms of mean, standard deviation, the values of R-G-B three band of fusion images obtained by the methods of GS, PCA and Wavelet are no different than the values of GF-1 images, but the values of fusion image obtained by the method of Brovey are quite different with the values of GF-1 image, spectral information serious distortion. In terms of information entropy and average gradient, the values of the information entropy and average gradient of fusion image obtained by the method of PCA are the biggest, GS and Wavelet followed, and the values of the fusion image obtained by the method of Brovey are the minimum. It shows that PCA method has an advantage in the increase of information, the expression of small detail and texture characteristics. In term of correlation coefficient, the values of the fusion image obtained by the method of Wavelet are the maximum. The spectral signatures of the image obtained by method of Wavelet are most correlated with the GF-1 image before fusion, the methods of PCA and GS followed.

Table 2 Quantitative Evaluation of Fusion of GF-3 and GF-1

Image	Band	Mean	Standard deviation	Information entropy	Average gradient	Correlation coefficient
GF-1	R	671.81	421.06	10.19	24.19	/
	G	804.81	351.15	10.15	27.74	/
	B	598.39	343.43	9.69	23.52	/
Brovey	R	3.92	3.56	3.43	1.28	0.25
	G	5.10	4.09	3.74	1.59	0.05
	B	3.50	3.19	3.26	1.16	0.16
GS	R	671.87	399.18	10.42	111.88	0.64
	G	804.68	326.96	10.08	103.90	0.54
	B	598.28	324.87	10.03	88.60	0.65
PCA	R	671.91	425.01	10.16	28.35	0.98
	G	804.98	359.19	10.11	40.81	0.95
	B	598.56	345.49	9.68	24.71	0.98
Wavelet	R	669.57	421.29	10.18	27.68	0.96
	G	802.11	350.93	10.13	38.27	0.93
	B	596.21	344.56	9.69	24.76	0.94

Analyzing the 5 indicators of the fusion images of GF-3 with GF-1 in Table 2, we can get some conclusions as follow: in terms of mean, standard deviation, the fusion images obtained by the methods of GS, PCA and Wavelet are similar to GF-1 image, but the fusion image obtained by the method of Brovey is quite different with GF-1 image. In terms of information entropy and average gradient, the values of fusion image obtained by the method of GS are the maximum, and the methods of PCA and Wavelet followed; In term of correlation coefficient, the values of the fusion image obtained by the method of PCA are the maximum.

5 CONCLUSION AND EXPECTATION

In this paper, the fusion experiments of Sentinel-1A and GF-1, GF-3 and GF-1 are performed respectively by the methods of Brovey, GS, PCA and Wavelet. By comparing and analyzing the effects of different fusion methods in the aspects of qualitative and quantitative, the following conclusions are obtained:

(1) By integrating visual effects and quantitative indicators of the fusion images of Sentinel-1A and GF-1, the methods of GS and PCA have advantages in image information and small details. The methods of Wavelet can maintain spectral information optimally. On the whole, in the fusion of two kinds of images, the effects of PCA are optimal in the four methods, Wavelet and GS followed.

(2) Comprehensive comparing and analyzing the images effects by different fusion methods of GF-3 and GF-1, the result of PCA shows a high correlation with GF-1 image before fusing in the aspect of visual effects and correlation coefficient indicators, then Wavelet followed. In the term of the expression of small detail and texture characteristics, GS has the advantage.

The images obtained by different sensors have different adaptability to fusion algorithm. It is necessary to select the appropriate fusion algorithm according to the characteristics of sensor and practical requirements. In this paper, four commonly used image fusion algorithms are selected for experiments. The results of experiments show that the methods of PCA and GS have advantage in the fusion of medium/high resolution Sentinel-1A/GF-3 with GF-1 images, and the methods can improve recognition ability. Sentinel-1 and GF-3 are SAR satellites that are widely used and free. The time of these two kinds data used for application is short, especially relevant data processing and applied research of GF-3 are still in progress. In this paper, the data of Sentinel-1A, GF-3 with GF-1 are respectively fused in similar resolution and different resolution, the results have some reference value for further application of Sentinel-1 and GF-3 data. However, because the experimental data and the research time are insufficient, the conclusions have some limitations. In the following study, the effects of speckle noise should be considered in image fusion. In order to increase the universality of the conclusion and promote the Sentinel-1 and GF-3 data fusion applications, more fusion algorithms need to be compared.

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