HYPERSPECTRAL RESOLUTION ENHANCEMENT USING HIGH-RESOLUTION IMAGERY WITH WAVELET PACKAGE ALGORITHM AND OPTIMAL INDEX PRINCIPLE

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ABSTRACT:

In this paper, aiming at image displaying and considering the characteristics of hyperspectral data and the requirements of practical application, a new hyperspectral image fusion method is proposed. This wavelet package image fusion approach is based on optimal index principle. The approach first selects optimal fusion bands of hyperspectral data by optimal index to construct synthesized low-resolution colour image and then fuses images by wavelet package algorithm which is based on multi-features in a region. The validity of the approach is testified by hyperspectral PHI data of shanghai area. Experiment shows that this approach can fuse hyperspectral data and high-resolution remote sensing data effectively and keep hyperspectral image's spectral physical characteristics and shape, thus satisfies the requirements of practical applications and provides a better condition for further researches.

1. INTRODUCTION

The development and application of hyperspectral techniques request more advanced approaches to process the hyperspectral remote sensing data with large dimensions, and hyperspectral image fusion technique is a hot but fairly difficult research field. Within optical remote sensor systems, image's spatial resolution is contradictive to its spectral resolution, which is that in case of known Signal-to-Noise, high spectral resolution (narrow spectral bands) is often obtained at the expense of spatial resolution. In order to solve this problem, hyperspectral satellite sensors such as LOUIS，ASTER，MODIS and so on are all equipped with high spatial resolution sensors, so that after fusion of spectral data and high-resolution spatial data, the spectral images spatial analytical characteristic is greatly improved and simultaneously its spectral physical characteristics and spectral information is efficiently kept (Zhang,2000).

Presently there are many fusion approaches for multi-spectral remote sensing image and high-resolution panchromatic image. Because of limited data resources, hyperspectral image fusion methods are relatively less (Park,2000). Analyzing the characteristics of hyperspectral images, adopting the thought of spectral fusion and based on image spectral recovering approach, a new spatial remote sensing data fusion model (SFSR) which first applies histogram equalization to hyperspectral image and high-resolution panchromatic image and then fuse them on each spectral band separately is proposed (Zhang,2000). On the basis of adaptive spatial decomposing approach and based on local information entropy, a multi-scale wavelet fusion method to extract feature images is proposed (Zhang,2002). And by feature selection principle based on contrast sensitivity, Wilson proposed a hyperspectral image fusion method to avoid the data processing problem caused by massive data (Wilson,1998). However, these multi-scale fusion methods usually fuse images based on single feature and definitely have some limits (Zhang,2004). Moreover, wavelet transformation fusion method can decompose, fuse and reconstruct images iteratively, but these operations are only conducted on image's low frequency part while its high frequency part (the image's detailed part) is ignored.

The combing of hyperspectral image and its spectrum and the characteristics of massive data make it difficult to fuse hyperspectral image while using common fusion methods. In this paper, aiming at image displaying and considering the characteristics of hyperspectral data and the requirements of practical application, a new hyperspectral image fusion method is proposed. This method can keep hyperspectral image's spectral physical characteristics and shape, and thus satisfies the requirements of practical applications and provides a better condition for further researches.

2. WAVELET PACKAGE FUSION METHOD FOR HYPERSPECTRAL IMAGE BASED ON OIF

Wavelet transformation fusion method can decompose, fuse and reconstruct images iteratively, but these operations are only conducted on image's low frequency part while its high frequency part (the image's detailed part) is ignored. However, wavelet package can efficiently avoid this problem and further decompose image's high frequency part on different scale, and thus obtain higher quality images. In practical applications, we are more concerned with improving the spatial resolution of fused image and ensure that its overall tone is consistent. Therefore, in this paper, an image fusing method based on OIF is proposed, the main idea of which is that: first select the optimal synthesizing bands of hyperspectral image by optimal index principle and obtain low-resolution synthesized colour image, then based on multi-features in a region, fuse it with high-resolution spatial image through adaptive wavelet package fusion algorithm to obtain high-resolution colour image. This method can avoid the limits brought by using single feature for fusion and make fusion information more abundant.

2.1 Band selection model by the optimal index principle

The greater the image's standard deviation the more information it will have, while the smaller the correlative coefficient between image bands, the more independent they will be and the less redundant information they will have. So here the optimal index model (OIF) can be adopted.

$$OIF = \sum_{i=1}^{3} S_i \Big/ \sum_{i=1}^{3} | R_{ij} | \tag{1}$$

Where S_i =standard deviation of the i image band

R_{ij} =correlative coefficient between i and j image band.

The numerator is the sum of the mean square error of three image bands, and the denominator is the sum of the correlative coefficient between them. It is clear that the smaller the correlation, the higher sparsely (information) these bands will have. The 3 image bands of the whole image data that give the highest OIF value are selected as the optimal image bands. If we are interested in some special regions, we can define them and get the optimal bands for them correspondingly.

2.2 Wavelet Package Algorithm

Wavelet package is composed of a few wavelet functions. Assume that there is a wavelet function cluster $\{w_n(x), n \in N\}$ and these functions have the following relationship (Zhu,2000).

$$w_{2n}(x) = \sum_k h_k w_n(2x-k) \tag{2}$$

$$w_{2n+1}(x) = \sum_k g_k w_n(2x-k) \tag{3}$$

When n=0, $w_0(x)=\varphi(x)$ and $w_1(x)=\psi(x)$, where $\varphi(x)$ is scale function, $\psi(x)$ is wavelet function, $\{h_k\}$ and $\{g_k\}$ are coefficients of low-pass and high-pass QMF filter and correspond to scale function and wavelet function respectively. Then $\{w_n(x), x \in N\}$ is called wavelet package determined by $w_0(x)=\varphi(x)$. According to equation (2) and (3), $w_n(x)$ can be reconstructed by $w_{2n}(x)$ and $w_n(x)$:

$$w_n(2x-l) = \sum_k \{p_{l-2k} w_{2n}(x-k) + q_{l-2k} w_{2n+1}(x-k)\} \tag{4}$$

Where $(\{p_k\},\{q_k\})$ is QMF filter corresponding to $(\{h_k\},\{g_k\})$. So the decomposing and reconstructing algorithm can be described as follows:

Assume that $A_n^{2^j} f(x)$ is approximation of wavelet package w_n on scale 2^j, which is

$$A_n^{2^j} f(x) = \sum_k S_{n,k}^j \cdot w_n(2^j x - k) \tag{5}$$

Where $S_{n,k}^j = 2^{\frac{j}{2}} \int_{-\infty}^{+\infty} f(x) w_n(2^j x - k) dx$

Then according to equation (1),(2), the decomposing algorithm is

$$\begin{aligned} S_{2n,l}^{j-1} &= \sum_m h_{m-2l} S_{n,m}^j \\ S_{2n.+1,l}^{j-1} &= \sum g_{m-2l} S_{n,m}^j \end{aligned} \tag{6}$$

And according to equation (3), the reconstructing algorithm is

$$S_{n,k}^j = \sum_l p_{k-2l} S_{2n,l}^{j-1} + \sum_l q_{k-2l} S_{2n+1,l}^{j-1} \tag{7}$$

2.3 Wavelet package fusion algorithm for hyperspectral data based on optimal index principle

To process hyperspectral data with wavelet package fusion algorithm, optimal bands have to be selected first by optimal index algorithm to obtain synthesized low-resolution color image, and based on which, registered panchromatic image is obtained. Then the color image and registered image are decomposed by wavelet package algorithm. On each decomposing layer, every image part, no matter high frequency part or low frequency part, of the previous layer is analyzed iteratively and comprehensively. After analyzing, sub-images that are decomposed from the original two images are fused through related fusing strategy, and the final fusion image is reconstructed through inverse transformation.

Usually, the more the wavelet package decomposing layer, the more details the fusion result will have. However, this is achieved at the expense of increasing computing amount. With the increasing of analyzing layer, the computing amount increases quite rapidly and information will be more and more heavily lost at the top layer. Thus wavelet package decomposing layers are sometimes chosen between 3 and 5 and more layers are not advisable. Here, wavelet package fusion algorithm for hyperspectral data based on optimal index principle can be summarized as follows:

(1) Select optimal bands of hyperspectral data based on optimal index and construct synthesized low-resolution color image.

(2) Initialize the wavelet package decomposing layer, the decomposing coefficients and so on.

(3) Design low-pass and high-pass decomposing filter that corresponds to the scale function $\varphi(x)$ and wavelet function $\psi(x)$ respectively and design low-pass and high-pass reconstructing filter at the same time.

(4) Decompose panchromatic image and synthesized hyperspectral color image on each layer by wavelet package decomposing algorithm and get the decomposed sub-images of both high and low frequency.

(5) Fuse the panchromatic and hyperspectral sub-images and, in order to extend the application area of information composition, we propose an adaptive wavelet package fusion algorithm based on region features and the brief process is:

(a) Assume the synthesized hyperspectral color image after wavelet package decomposing is $A(x,y)$ and the panchromatic image is $B(x,y)$, separate the colors of image $A(x,y)$ to get three sub-images defined as $A_j^k(x,y)$ ($k=1,2,3$ and j is scale coefficient) and then apply histogram equalization to image $B(x,y)$ and $A_j^k(x,y)$.

(b) Open a $M\times N$ window (usually 3×3) for image $A_j^k(x,y)$ and $B(x,y)$, and in every image window, compute the square error D_i, energy E_i and information entropy S_i .

(c) Calculate the pixel's weigh on image $A_j^k(x,y)$ and $B(x,y)$

$$W_i = a * E_i + b * D_i + c * S_i ; \tag{8}$$

Where a , b , c are weights of every feature and their default value is 1.

(d) Get the fused sub-images by the following equation

$$F_j^k(x,y) = (A_j^k(x,y)\cdot W_a + W_b \cdot B^k(x,y))/(W_a + W_b) \tag{9}$$

Interpolate reconstructed image inversely by the above wavelet package reconstructing filters and get the final fusion image.

3. HYPERSPECTRAL IMAGE FUSION EXPERIMENTS

3.1 Experimental data

The color image composition based on optimal bands and the fusion of high-resolution panchromatic image and hyperspectral image are two main parts of our experiment. The data used in our experiment was received in Oct 2003. It is PHI data of Shanghais Physics institution and is composed of 124 wave bands ranging from 400 to 850nm. The flight altitude is 2163 meters and the latitude and longitude of the data is 31.18°-31.20° and 121.46°-121.51° respectively. In the original data, we selected the Yangpu bridge region (647×721 pixels) as our research interest. Additionally, for our fusion experiment and to obtain high-resolution color fusion image, we collected some high-resolution panchromatic images in the same area.

3.2 Results and analysis

In order to test the validity of our methods, we conducted a few experiments by the above PHI data. And the detailed fusion process is shown as follows.

(1) Preprocess the hyperspectral data, and this step includes the correction of radiation, atmosphere, and geometry and so on [8].

(2) Preprocess the high-resolution images with geometry correction, select the optimal hyperspectral bands by the optimal index model and construct synthesized low-resolution color image.

(3) Match hyperspectral and high-resolution images. This pixel matching step is quite important for image fusion and aims at eliminating the differences between images obtained by different sensors on the aspects of resolution, time, angle and confirming that every pixel of both images corresponds to the same spatial position. During the registering process, select some evenly distributed feature points on both images, and then register the images by these points through quadratic polynomial algorithm. After registering, resample the images through bilinear interpolation algorithm and output the images to end the image registering process.

(4) Fuse the registered low-resolution color image and high-resolution panchromatic image by wavelet package algorithm described above.

Practically, we can constraint the selection of the red, green and blue band of the synthesized image according to the wavelength range and the original images' center to reduce the blindness and amount of computing. In our experiments, the red band was confined to the 43-46th bands, the green band was confined to the 22-43rd bands and the blue band was confined to the 1-21st bands. The result of optimal bands was the 55th, 33rd and 10th for the red, green and blue band respectively and the corresponding optimal index was 56.881. Figure 1 is synthesized low-resolution color image by optimal bands. It can be seen that the synthesized image greatly keeps the spectral characteristics of the original information and can provide favorable conditions for image understanding. Figure 2 and 3 are the final fused images of the Yangpu bridge region, and it is clear that the fused images' spatial resolution and clearness are greatly enhanced: automobiles on the bridge have more clear forms; marks in the garden's center are more prominent; and the overall color information is satisfying.

Figure 1. Synthesized hyperspectral image

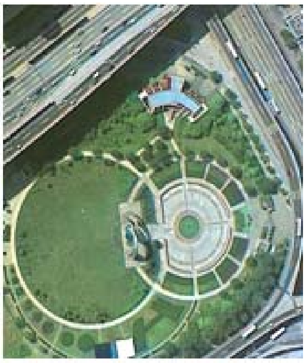

Figure 2. fusion image Figure 3. part of the fusion image

Information entropy is an effective index to measure the degree of image's information; mean gradient can reflect the contrast, texture characteristic and clearness of images; correlation coefficients can reflect the similarity between the fused image and the original hyperspectral image. Thus, we choose information entropy, mean gradient and correlation coefficients and other measures to conduct quantitative analysis and the results in shown in table 1.

Fusion Algorithm	Information entropy	Standard error	Mean	Correlation coefficients
Original Panchromatic Image	7.650	57.598	9.529	-
Original hyperspectral image	10.756	29.307	1.777	-
Fusion image	13.095	57.78	9.566	0.838

Table 1. Quantitative analysis results of fused image

From table 1, it can be seen that the information entropy, mean gradient and correlation coefficients of the fused image by wavelet package fusion method based on optimal index principle are greater than the original image. In other words, it means that the fused image has richer information, greatly keeps the original hyperspectral data's spectral characteristic and enhances the degree of image's transparency and sharpness.

4. CONCLUSIONS

Image fusion for hyperspectral data and high-resolution data is an emerging technology with the development of remote sensing imaging technology. It has tremendous application future on such areas as city planning, environment monitoring, land utilization, military reconnaissance and so on. However, most of the current researches and attempts are just tentative. To convert these theories and techniques into generalized rules and to apply them to remote sensing area successfully remains a long way. In this paper, after studying some related algorithms in the image fusion area, we proposed a wavelet package fusion algorithm for hyperspectral image based on optimal index band selection principle and experiments bring us to make the conclusion that this approach can generate hyperspectral fused images effectively and robustly.

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4.1 References

[1] Zhang Bing,1997. Hyperspectral data mining supported by temporal and spatial information, Ph.D. dissertation, Institute of Remote Sensing Applications of Chinese academy of sciences, Beijing, pp. 80-88.

[2] Jong-Hyun Park, Ryutaro Tateishi a, Ketut Wikantika,2000, Multisensor data fusion using multiresolusion analysis. *ISPRS*, pp. 987-1002.

[3] Zhang Jun-Ping, Zhang Ye,2002, Hyperspectral image multi-solution fusion based on local information entropy, Chinese Journal of Electronics, 11(2), pp. 163-l66.

[4] Wilson Terry A, Regers Steven K, Matthew Kabrisky,1988, Perceptual-based image fusion for hypetspectral data, IEEE Trans, On G.R.S, 35(4), pp. l007-1017.

[5] Zhang Jun-Ping, Zhang Ye,2004, Hyperspectral image classification based on multiple features during multiresolution fusion, J. Infrared Millim Waves, 23(4), pp. 345-348.

[6] Zhu Shu-Long, Geng Ze-Xun,2000, *Wavelet transforms for remote sensing image processing*, Beijing, pp. 24-25.