FUSION OF REMOTE SENSING IMAGE
BASE ON THE PCA+ATROUS WAVELET TRANSFORM

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ABSTRACT：

On the basis that the PCA transformation and additive wavelet transformation have their own advantages and disadvantages ——higher spatial resolution can be acquired from the PCA transformation; however, more serious distortion of spectral characteristics can happen as well. While, the àtrous wavelet transformation is able to preserve spatial information; however, the result is lack of high spatial resolution. A new technique, based on additive wavelet decomposition and PCA transformation was developed for the merging and data fusion of such images in this paper. Firstly we must get a fusion image by using the PCA transformation to merge the multispectral image and the high-resolution panchromatic image. Then we get the new principle components for the new multispecral image, while greatly parts of data information is included in the first component of the fused image. And then we apply the atrous wavelet merger to merge the multiresolution image and the first component of the fused image by PCA merger which substituted of the high-resolution panchromatic image. The new method is capable of preserving its spectral content while enhancing the spatial quality of the multispectral image to a greater extent.

1 INTRODUCTION

There are several situations that simultaneously require high spatial and high spectral resolution in a single image. This is particularly important in remote sensing. In other cases, such as astronomy, high spatial resolutions and high signal-to-noise ratio (SNR) may be required[1]. However, in most cases, instruments are not capable of providing such data either by design or because of observational constraints. For example, in remote sensing, the SPOT satellite platform provides high-resolution (10m pixels) panchromatic data, while LANDSAT TM satellite data provides low-resolution (30m pixels) multispectral images.

One possible solution comes from the field of data fusion. A number of methods have been proposed for merging panchromatic and multispectral data. The most common procedures are the Principal Component Analysis transform based methods (PCA mergers). However, the PCA methods produce spectral degradation. This is particularly crucial in remote sensing if the images to merge were not taken at the same time. In the last few years, multiresolution analysis has become one of the most promising methods for the analysis of images in remote sensing. Recently, several authors proposed a new approach to image merging that uses a multiresolution analysis procedure based upon the discrete two-dimensional (2-D) wavelet transform[3,4]. We also carried out a preliminary study of the wavelet-based method in combination with image reconstruction. Multiresolution analysis based on the wavelet theory permits the introduction of the concepts of details between successive levels of scale or resolution. Wavelet decomposition is increasingly being used for the processing of images. The wavelet approach preserves the spectral characteristics of the multispectral image better than the standard IHS methods.

2 WAVELETS AND WAVELET TRANSFORM

The method is based on the decomposition of the image into multiple channels based on their local frequency content——wavelet transform can produce the images in different resolution. Wavelet represention refers to both spatial and frequency spaces. It can show a good position of a function (a.k.a image) in spatial and frequency space. The wavelet transform provides a framework to decompose images into a number of new images, each one of them with a different degree of resolution. While the Fourier transform gives an idea of the frequency content in our image, the wavelet representation is an intermediate representation between the Fourier and the spatial representation, and it can provide good localization in both frequency and space domains. There are different approaches to do wavelet decomposition. One of them is Mallat algorithm which uses wavelet functions such as Daubechies functions (db1, db2 ,…). In this study we used the discrete wavelet transform algorithm known as atrous algorithm, (with holes) which used dyadic wavelet to merge nondyadic data in a simple and efficient procedure. In this algorithm a successive convolution using a filter was applied to the discrete wavelet transform. The wavelet transform of a distribution can be expressed as[2]：

$$R=(\frac{1}{16},\frac{1}{4},\frac{3}{8},\frac{1}{4},\frac{1}{16})\otimes\begin{pmatrix}1/16\\1/4\\3/8\\1/4\\1/16\end{pmatrix}=\frac{1}{256}\begin{bmatrix}1 & 4 & 6 & 4 & 1\\4 & 16 & 24 & 16 & 4\\6 & 24 & 36 & 24 & 6\\4 & 16 & 24 & 16 & 4\\1 & 4 & 6 & 4 & 1\end{bmatrix}$$

- To use convolution function directly.
In each step we get a new version of the image I_1, I_2, …..The wavelet coefficient is defined as follows:

$$wc_L = I_{L-1} - I_L \qquad L = 1,2,....,n$$

So if we decompose an image *I* into wavelet coefficients, then we can write:

$$I = \sum_{l=1}^{n} wc_l + I_r$$

where I_r is a residual image.

In this approach all wavelet planes have the same number of pixels as the original image. There are two approaches for image fusion based on wavelet decomposition: 1) substitution method which replaces some wavelet coefficients of the multispectral image by the corresponding coefficients of the high resolution image and 2) additive method which adds high-resolution coefficients to the multispectral data. The first method of the wavelet decomposition in combination with the PCA method we applied to merge multispecral image and panchromatic image in this study. But the result showed that the PCA transformation and additive wavelet transformation has their own advantages and disadvantages——more serious distortion of spectral characteristics in the PCA (Principal Component Analysis) transformation while better in preserving spectral information and lack of spatial in the atrous wavelet transformation. So, we developed a new technique, based on additive wavelet decomposition and PCA transformation, for the merging and data fusion of such images.

3 IMAGE FUSION ALGORITHM

1.1 Preprocessing of input images

In image fusion, the first step is to prepare the input images for the fusion process. This includes registration and resampling of the input images (Zhou,1998). Registration is to align corresponding pixels in the input images. This is usually done by geo-referencing the images to a map projection such as UTM (Universal Transverse Mercator). If the images are from the same sensors and taken at the same time, they are usually already co-registered and can be directly used for fusion processing. However, if the images are from different sensors, and even if they are georeferenced by the image vendors, a registration process is likely still necessary to ensure that pixels in the input images exactly represent the same location on the ground.

Image registration can be performed with or without ground control. The most accurate way is to rectify the images using ground control points. However, in most cases, it is not possible to find ground control points in the input images. In such situations, taking the panchromatic image, which has a better spatial resolution, as the reference image and registering the multispectral images with respect to the panchromatic one can be a good solution to refine the rectified multispectral images.

1.2 Implementing wavelet transform

This approach was done in the following way. Firstly a fusion image was obtained by using the PCA transformation to merge the multiresolution image and high-resolution panchromatic image.

Then we got the new principle components from the new multispecral image, with most image information contained in the first component of the fusion image. Finally, the àtrous wavelet transformation was applied to merge the multispectral image with the first component generated from the PCA transformation to substitute the original high-spatial resolution panchromatic band.

In the substitution method the wavelet coefficients of multispectral image were discarded and substituted by the wavelet coefficients of the new first component of the PCA fusion image.
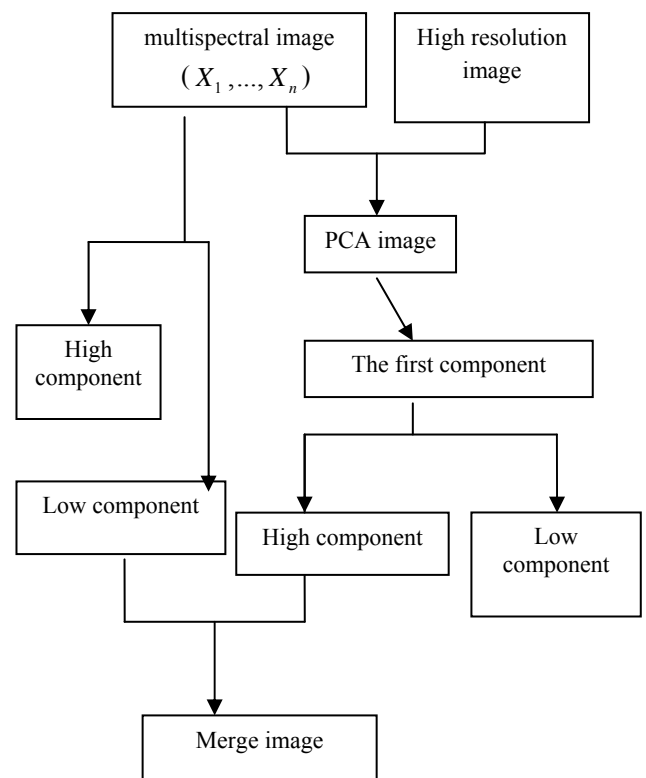

Figure.1. Flowing chart of image fusion based on the PCA+àstrous method

1.3 Test Data

Now we give the specific operational procedure for the proposed PCA+àtrous image fusion approach. The operational procedure is a generic one, although Quickbird images were taken as an example in order to illustrate the method. First, multispectral QuickBird images (ground resolution was 2.8 meters) over the pyramids are fused with the QuickBird panchromatic image (ground resolution was 0.7 meters), they were both acquired in 2003.

4 RESULTS AND EVALUATION

4.1 Fusion of QuickBird images

Since both images are taken at the same time and from the same sensor, no registration or rectification is needed. The resolutions of the multispectral image and the panchromatic one are 2.8 m. and 0.7 m respectively. They have been

registered strictly at the same scale. We fused the images with different methods including PCA and astrous. These images were used to be compared with the image fused by PCA+astrous.

4.2 Visual and Quantitative Evaluation

4.2.1 Visual Evaluation: First the fused images were evaluated visually. It is clearly seen from the pictures in Figure 2 that the spatial resolutions and the spectral resolutions of the images after the fusion are improved, in comparison to the original images. The spectral information in the original panchromatic image has increased, and the structural information in the original multispectral images has also been enriched. Hence, the fused images contain both the structural details of the higher spatial resolution panchromatic image and the rich spectral information from the multispectral images. In the original QuickBird images, it is very difficult to discern some physical features like small buildings.

But, the colors of the features in the fused images are changed. This color distortion effect is the largest in PCA method. We find that (c) fully conserve spatial information of high-resolution image, but evident spectral distortion exist. Among these three methods, astrous transformation gives the best result in terms of color conservation. The spectral characteristics of (d) are closest to the original multi-spectral image than other fused images, and the spectral characteristic of (d) is similar to (b).

However, the result obtained from PCA+astrous wavelet transform approach is superior to those two results, as the colors of the features in original multispectral images are nearly the same with the fusion image just based on the astrous wavlet.

But the PCA+astrous wavelet gives a better spatial resolution when compared to the results from other fusion methods. So in this paper, compared with the fused result just from astrous wavlet or the PCA alone, the fused result obtained from the PCA+astrous wavelet transform has a better visual effect in Quickbird image fusion in Figure 2.

4.2.2 Quantitative Evaluation

In general, a good fusion approach should retain the maximum spatial and spectral information from the original images and should not damage the internal relationship among the original bands. So secondly we evaluate the performance of the fusion method based on PCA+astrous wavelet transform using image quality indexes. Based on these criteria, the indexes we selected are average value, standard difference, entropy, average grads, fractal dimensions and correlation coefficients. Average value can show the distribution of the image grayscale in the rough. Standard difference and entropy can measure the information abundance in the image. Average grads shows exiguous contrast, varied texture characteristic and definition of the image.

Table 1 presents a comparison of the experimental results of image fusion using the PCA image fusion method, the astrous wavelet-based image fusion method, and PCA+astrous method in terms of combination entropy, the average gradient and the correlation coefficient[5].

The combination entropy (C.E.) represents the property of combination between images. The larger the combination entropy of an image, the richer the information contained in the image. In Table 1, the combination entropy of the PCA+astrous-based image fusion is greater than those of other methods. Thus, the PCA+astrous-based image fusion method is better than the astrous wavelet and PCA methods in terms of combination entropy.

The mean gradient (M.G.) reflects the contrast between the details variation of pattern on the image and the clarity of the image. And the correlation coefficient (C.C.) between the original and fused image shows the similarity in small size structures between the original and synthetic images. The higher the value, the more similar the fused image to the corresponding original image, which in turn indicates a good spectral information retain in the fused results. Results in Table shows that the astrous wavelet transform approach and the PCA+astrous keeps over 90% of the spectral content of all original multispectral bands, the result of the astrous is the best and the PCA+astrous-based image fusion is only slightly lower.

But the mean gradient of the PCA+astrous-based image fusion method is greater than those of the astrous wavelet based image fusion method, since the details have been enhanced in fusion process, roads, bridges, airports, rivers and other objects are distinguished more easily. As previously stated, if the object of image fusion is to construct synthetic images which are closer to the reality they represent, then the PCA+astrous-based image fusion method meet this objective very well. This is one of the main advantages of using the PCA+astrous transform for image fusion.

In a word, though there is a slight spectral distortion in the fused image based on PCA+astrous wavelet transform, its spatial resolution and details texture have been enhanced remarkably. This demonstrates that the fusion method based on PCA+astrous wavelet transform is better than the fusion method just based on asttrous wavelet transform or PCA transform.

All the above analysis suggests that the wavelet based fusion approach provides overall the best results in the methods used in our study. Based on the experimental results obtained from this study, the PCA+astrous-based image fusion method is very efficient for fusing Quickbird images. This new method has reached an optimum fusion result.

Method	C.E	M.G	C.C
Original images (band 1、band2、band3、band4)	4.80364	5.9237	_____
	4.91436	6.2839	
	5.01511	6.6029	
	6.37158	7.7767	
Image fused by PCA (band 1、band2、band3、band4)	7.16106	17.3162	0.62786
	7.17243	17.2208	0.62657
	7.21094	17.6439	0.62712
	7.19666	18.3797	0.6512
Image fused by astrous (band 1、band2、band3、band4)	7.11928	15.8315	0.94334
	7.22269	16.2062	0.94166
	7.25106	16.3050	0.94431
	7.16074	17.0117	0.89956
Image fused by PCA+astrous (band 1、band2、band3、band4)	7.12787	19.8423	0.90557
	7.36655	20.9268	0.90967
	7.36208	20.8359	0.91660
	7.29436	21.4049	0.86847

Table.1. Information statistics of Quickbird image

5. CONCLUSIONS

We have presented a newly developed method based on the PCA+astrous transform for fusing images. In this paper, an experimental study was conducted by applying the proposed method, and also other image fusion methods, for fusing Quickbird images. A comparison of the fused image from the astrous wavelet and PCA method was made.

This study is a successful experience with the PCA+astrous wavelet transform based fusion approach. It is shown that proposed wavelet transform approach improves the spatial resolution of a multispectral image while it also preserves much portion of the spectral component of the image.

This topic along with further formulation of fusion quality will be our future effort of study.

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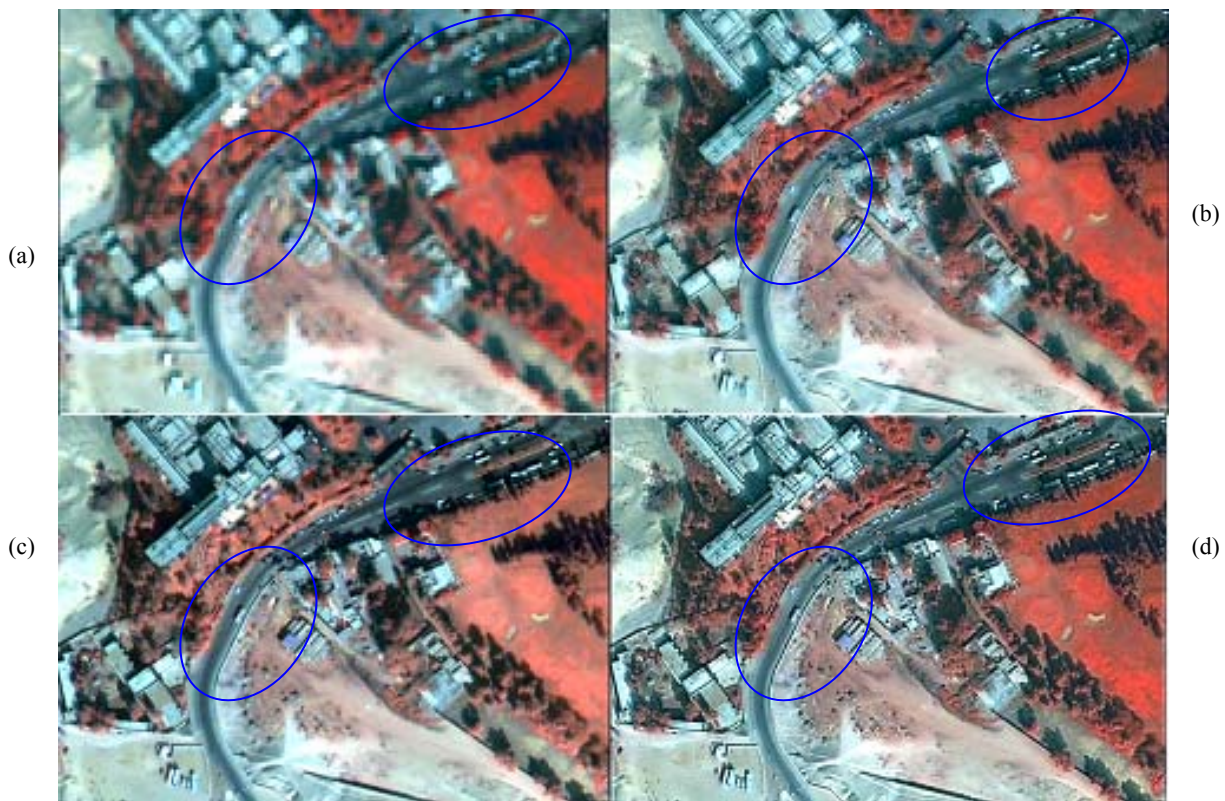
Figure.2 (a) Detail of the Quickbird multispectral image. (b)Result of the fusion by astrous wavelet method. (c)Result of the fusion by PCA. (d)Result of the fusion by PCA+astrous wavelt method.