MULTI-SPECTRAL IMAGE FUSION METHOD BASED ON WAVELET TRANSFORMATION

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KEY WORDS: Image fusion; Wavelet transform; Weighting average; Threshold; Characteristic of human vision system

ABSTRACT:

The paper focuses on image fusion between multi-spectral images and panchromatic images using a wavelet analysis method with good signal processing and image processing traits. A new weighting technique is developed based on wavelet transformation for the fusion of a high spatial resolution image and a low-resolution, multi-spectral image. The method improves a standard wavelet merger for merging the lower frequency components of a multi-spectral image and its high spatial resolution image by means of local deviation rules with weighting average. And then the merged image is reconstructed by an inverse wavelet transform using the fused approximation and details from the high spatial resolution image. Also, a multi-spectral images fusion algorithm is proposed based on wavelet transform characteristic of human vision system. Firstly, perform a wavelet multi-scale transformation of each source image. Then a new fusion regular is presented based on human vision system corresponding high (low) frequency components are divided into several blocks, and contrast error of every block is calculated, an adaptive threshold selection is proposed to decide which should be used to construct the new high (low) frequency components. Finally, the fused image is obtained by taking inverse wavelet transform. The experimental results show that the new method presented is clearly better in not only preserving spectral and improving spatial presentation, but also avoiding mosaic occurring.

1. INTRODUCTION

The image fusion is that the multiple images which obtains from a sensor or many sensors synthesizes an image, in which the information from the multiple primitive images can be reflected so as to analyze and judge the target more precisely and comprehensively. Because both the images gain from multi-sensors have the redundancy and the complement, the multi-sensor image fusion technology may enhance the reliability of the system and also enhance the use efficiency of the pictorial information [1]. At present, various militarily significant states in the world competitively invest massive manpower, physical resource and financial resource to carry on the information fusion technology and have obtained magnificent research results. Take US for example, the expense that is used, every year, in the research of information fusion technology amount to more than 100,000,000 US dollar. The image fusion technology in such aspects as medicine, remote sensing, computer vision, weather forecast has also been widely applied. Especially in the computer visual aspect, in the astronautics and aviation multi-delivery platform, the massive remote sensing image fusion obtained from each kind of remote sensor in different spectra, different wave bands, different temporal or different angles provides good processing method for information highly effective extraction, and obtains obvious benefit. In the last few years, along with the information fusion technology development, obtaining the remote sensing image in double high resolution with the post-processing method has become the essential target and the duty of the remote sensing information fusion, and has formed many algorithms, like IHS algorithm, PCA algorithm and that based on wavelet transformation algorithm.

2. IMAGE FUSION BASIC FLOW

The commonly classification of image fusion is based on the image attribute, which divides image fusion into three levels, namely picture element level, characteristic level and policy-making level fusion. The object of image fusion data may can be divided into the optical image and the non-optical image according to the image formation way. The basic processes of

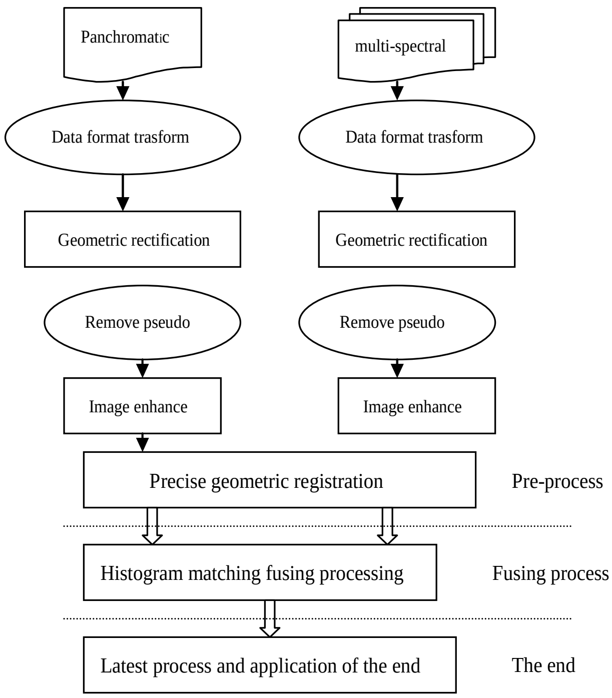

Figure 1 Basic procedure of image fusion between multi-spectral images and panchromatic images

multi-spectrum image and full-color image fusion system are as shown in Figure 1.

3. WEIGHTING IMAGE FUSION BASED ON WAVELET TRANSFORMATION

The fusion method based on the wavelet transformation has retained and inherited the main merits of tower-shaped transformation fusion method [2-4]. Simultaneously, because the orthogonal wavelet transformation has non-redundancy, the image data quantity after wavelet transformation will not increase. By using the direction of wavelet transformation, a better visual effect of fusion image will be able to obtain based on the vision characteristics that the human eye have different resolutions to high frequency component of different directions.

3.1 Image fusion based on wavelet transformation

The image fusion realization requests to extract information (details) from each source image and obtains the effective demonstration in the final fusion image. According to the general theory of imagery processing, the image information (details) is concluded in the image high frequency component, therefore, the key point of image fusion research is to seek an appropriate processing method of fusing detailed information of source image respectively, that is, how will the information be fuse-processed effectively in the corresponding frequency band. According to the multi-resolution analysis theory, the source image after the wavelet transformation, the inner tube signal row D_{j-1}^1 , $\mathrm{D}_{\text{j-1}}^2$, $\mathrm{D}_{\text{j-1}}^3$, contains separately the image high frequency component of corresponding frequency directed in normal, horizontal and 45º of the image， therefore, using the image tower-shaped structure after wavelets decomposing, to carry on fusion processing separately according to different transformation level and different frequency band, the information detail from different images can be fused effectively.

Carry on N wavelet transformation to the two-dimensional picture, and it will finally get some (3N+1) different frequency bands, which contains a 3N high frequency bands and a low-frequency band. The image fusion program based on wavelet multi-dimensional transformation is shown as in Figure 2. Take two image fusions as an example, many image fusion methods may be analogized from this regarding. Suppose A and B are two primitive images, F is the image after fusion, its basic fusion steps are as follows:

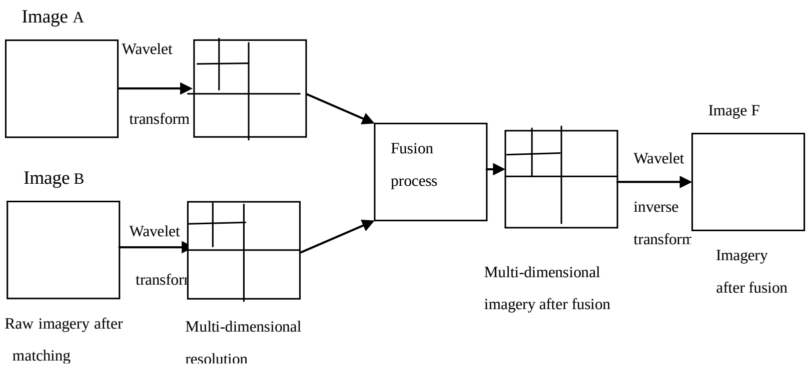

Figure2 Procedure of wavelet multi-dimensional fusion

(1) Carry on the wavelet transformation separately to each source image to establish various images of the wavelet tower-shaped transformation.

(2) Carry on fusion processing separately to each transformation level and to different frequency components of each transformation level using different fusion operator, to finally obtain fusion wavelet pyramid.

(3) Carry on the wavelet inverse transformation (i.e. to carry on image restructuring) to wavelet pyramid after fusion to obtain restructuring image namely for fusion image.

When fusing the multi-spectrum image and the high spatial resolution image, David proposed one method (which was afterwards called the WT method), which simultaneously carries on the wavelet transformation to the multi-spectrum image and the high spatial resolution image, combines the low frequency component of multi-spectrum image with the high frequency component of high spatial resolution image, then carries on the wavelet inversion, and finally obtains a multi-spectrum image of the high spatial resolution. That is the initial wavelet transformation fusion law [5].

In practical application, in order to prevent the spectrum distortion caused by replacement in the fusion process, it is necessary to enlarge various relevance of wave bands image before the transformation wavelet through the histogram matched various wave band images, to reduce the spectrum deviation of fusion image.

The WT method is always considered as the superior high resolution and the multi-spectrum image fusion method. But it has also a shortcoming: Because the wavelet transformation has localization in the good air zone and the frequency range, it may well retain the spectrum information in the multi-spectrum image, but because this method has discarded low frequency component of the high spatial resolution image, it results in the ringing effect in the inverse transformation.

3.2 Weighting image fusion algorithm based on wavelet transformation

As we know, the spatial variation surface of the remote sensing image grey level expresses has the characteristics of stochastic changes. But analyzed from the spatial frequency spectrum angle, they may all be transformed to the spectrum which is composed of different spatial frequency spectrum waves.

Regarding the different remote sensing images in the identical area, its difference is not in the low frequency part, but in high-frequency part. In other words, its low frequency part of the spatial frequency spectrum is the same or similar, and the remarkable difference is only in the high-frequency part. Therefore, it can be processed according to the low frequency and the high frequency by using different fusion rules.

To the low frequency components, $T_{LL,}$ P_{LL} , we use the simple weighted average operator, namely: $T_{LL}^{'} = K_T \times T_{LL} + K_P \times P_{LL}$, in which $K_{T,}$ K_P are

The comparison fusion process is as follows:

(1) Determine a size of an air zone window (for instance, may take 5×5), and then divide W_P and W_T into some sub-block images of the size of this window.

(2) Carry on the value distribution statistics to each sub-block image, and calculate its mean value and the standard deviation.

(3) Determine the data fusion value of each sub-block image as $W' = \mu_P \times W_P + \mu_T + W_T$, in which μ_P and μ_T is the weighting factor of each sub-block of W_P and W_T. If the fruit block standard deviation of W_P is bigger than the image sub-block standard deviation of $W_{T,}$ then $\mu_P \geq \mu_T$, else $\mu_P \langle \mu_T$.

Recalculate (2) and (3), to get the fusion value of all sub-block images. Thus the new high-frequency unit W´ is obtained. Then add the high-frequency component and the low frequency ingredient to obtain the fusion low frequency component,

weight coefficient. Because the low frequency part is mainly taken from multi-spectrum image, $K_T \rangle K_P$. And To the high frequency components, we proposed a method according to the image statistical property to process the fusion based on the biggest criterion to partial region standard deviation [6].

Divide two high frequency images into certain sub-block images, and then compare the standard deviation of corresponding sub-block images. The bigger the standard deviation of a sub-block image, the bigger the weight is.

namely： $T_L^{'} = T_{LL}^{'} + W'$. Finally combine this new low frequency component with the high frequency component of high spatial resolution image to achieve the final fusion result in wavelet inversion.

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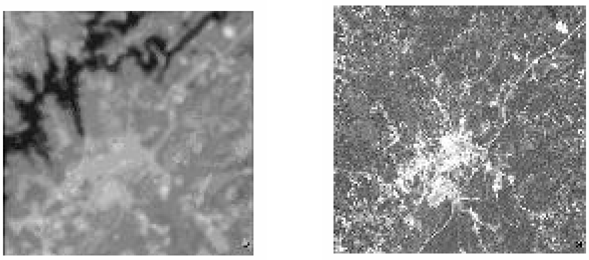
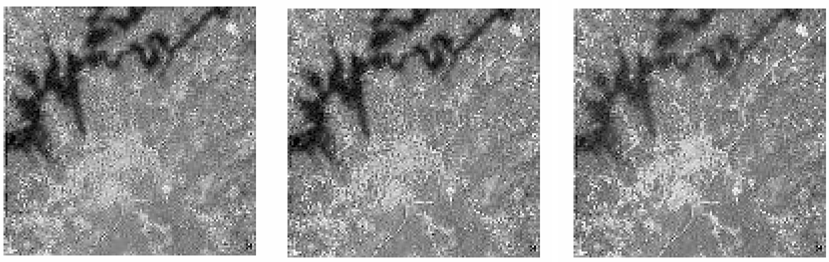
3.3 Fusion result appraisal

In order to confirm the accuracy and the validity of the method, we have selected some region terrain general picture Landsat TM multi-spectrum image and the SPOT image to carry on the fusion experiment. First we carry on the strict matching and processing, analyze respectively the wavelet of the two images, and then process it according to the method as above-mentioned. Thus the final fusion image is obtained. In order to be compared, these two images are processed with the WT method. The result is shown in figure 3.



(1) Multi-spectral image (2) high-resolution image



(3) WT method J=1 (4) WT method J=2 (5) the new method in this paper

Figure3 Raw image and fusion image

The results of different fusion method may be judged visually. The merit is direct, simply, which makes the qualitative appraisal direct according to the contrast after imagery processing: The shortcoming is its strong subjectivity. In order to evaluate the fusion effect objectively and quantitatively, we analyzed the information contained in the fusing image. We use the visual distinction firstly, and then we carry on the quantitative analysis. (1) is the Landsat TM multi-spectrum

image, (2) is the SPOT image, (3), (4) is the fusion image in WT method when wavelet transformation exponent number J=1, 2, (5) fusion image which obtains for this article method.
From the chart we may see, the result basically maintained the original map spectral characteristic regarding WT method when J=1, but image spatial detail performance ability is not high, the entire image is quite dim, the edge characteristic is not very clear like rivers edges, the enhancement effect is not very good. Regarding the result of WT method J=2 fusion, the ringing effect appeared, to create the fuzzy texture. By the method proposed in this paper we obtained the image (5) in which not only the outline is quite clear but the river boundaries is clearer than (3) and (4). Moreover the spectral characteristic maintains quite well.

When we carry on the quota analysis comparison, we use the correlation coefficient and spectrum tortuosity of the image to carry on the appraisal. Table 1 gives the parameter contrast of the image fusion results, and it can be easy to see from the parameters in the table that the method proposed in this paper has a very good effect in enhancing the spatial texture characteristic of multi-spectrum images and in maintaining spectrum information.

Method types	spectrum tortuosity	Correlation coefficient	
		SPOT Image	TM multi-spectral Image
Method WT J=1	19.03	0.61	0.79
Method WT J=2	24.42	0.72	0.74
The new method	24.05	0.83	0.74

Table1 Comparison of images fusion result

4. MULTI-SPECTRUM IMAGE FUSION BASED ON WAVELET TRANSFORMATION AND VISUAL CHARACTERISTICS

Although the fusion effect of wavelet transformation method is relatively ideal, its transformation restructuring is actually a process of the high pass and the low pass filter, and, to a certain extent, loses some edge information in the primitive image, as a result of which the ringing effect in fusion image appears. Therefore, when the image fusion is carried on, the wavelet transformation and other alternative means are often combined. This paper proposes a new image fusion method in which the wavelet transformation is combined with the features of human vision system. This method can not only enhance the spatial detail ability of multi-spectrum image, maintenance the spectrum information, but also avoid strengthening the result ringing effect.

4.1 Human eye vision system

The image is to be looked at by humans, therefore the imagery processing should follow the features of human vision system. The vision is the result that images are left in human eyes. The complexity of visual processing has not have been understood and mastered by human beings at present. But people have discovered some visual phenomena, such as visual threshold, visual masking effect. If these features of human vision system are fully used in the imagery processing, the image quality will be greatly improved [7-8].

4.2 Fusion algorithm based on wavelet transformation and features of human vision system

Fusion method theory is based on: Through the statistics of the value distribution, the sub-graph of source image A and B after wavelet transformation has such characteristics:

(1)The data change scope in the original map region is identical to that of the sub-graph corresponding region.

(2) Regarding the different source images of identical goal or object, the data value of its low frequency image in corresponding region is the same or similar, but there is a remarkable difference in the high frequency sub-graph. The above-mentioned characteristic of the wavelet transformation has provided the theory basis for the choice of the effective fusion method. As for combining the wavelet transformation with the feature of human vision system, a new fusion method is brought up in this paper.

(1) Carry on the geometry correction to the multi-spectrum image and the high resolution image respectively, use the geometry matching method based on the region, and then match the multi-spectrum image with the high resolution image.

(2) Carry on a step wavelet resolving to the matched multi-spectrum image and the high resolution image to obtain respectively the low frequency component and the high frequency detail component.

(3) Carry on the uniformity method fusion to the two corresponding images of the high frequency and the low frequency sub-graph respectively, the processes are:

① Dissect the two images into some sizes for N×N blocks. Suppose A_i and B_i expresses the block of image A and B separately.

② Calculate the uniformity measure of each block according to the formula which literature [9-10] provides. Suppose J(Ai) and J(Bi) are respectively the uniformity measures of Ai and Bi.

③ Compare the uniformity measure of the corresponding block of the two images, and obtain the fusion image ith block Fi

$$F_i = \begin{cases} A_i & J(A_i) \geq J(B_i) + TH \\ B_i & J(A_i) \leq J(B_i) - TH \\ (A_i + B_i)/2 & \text{otherwise} \end{cases}$$

Among them, TH is the threshold value parameter.

④ In turn carry on the above operation to all image blocks, the new fusion image is obtained.

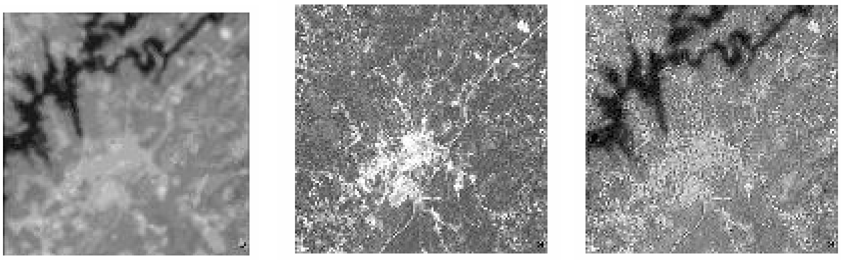
⑤ Carry on the wavelet inversion to the obtained high frequency and the low frequency sub-graph, and obtain the fused multi-spectrum image.

In this algorithm, threshold value TH needs to be determined. The method of choosing the fixed threshold value on experience, to be frank, is unreasonable because the threshold value is changing along with the system mode, the model deviation, the system reference input and the noise and so on, but the fixed threshold value is not able to adapt these changes obviously. Therefore, we need to enable the system to auto-adapted itself to choosing the threshold value. The existing methods of choosing the threshold value mainly are: method based on statistics, method based on knowledge and method based on analytical model [11]

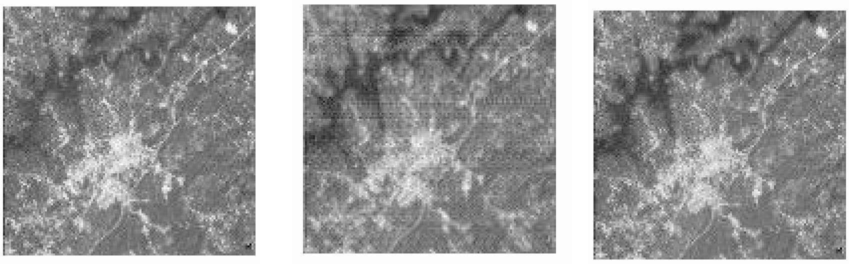
4.3 Experimental results and appraisal

In order to confirm the accuracy and the validity of the method, we still select the multi-spectrum image and the high spatial resolution image of some region terrain landform to carry on the fusion experiment. First carry on the strict matching and processing, separately carry on the wavelet transformation to it, then process according to the method of choosing threshold value proposed in this chapter, and the final fusion result image is obtained.

To be compared, these two images have been processed by using the traditional wavelet method. The results are as in Figure 4.



(1) Multi-spectral image (2) High-resolution image (3) Wavelet image



(4) large threshold (5) Small threshold (6) Adaptive threshold

Figure 4 Raw image and fusion image

(1) is the Landsat TM multi-spectrum image, (2) is the SPOT image, (3) is obtained by using the traditional wavelet method, (4)、(5)、(6) are respectively the fusion images obtained when using different threshold value. It can be seen from the figure, the fusion images obtained by using the traditional wavelet method basically maintain the spectral characteristics of the original ones, but the ability to perform spatial details was not high; the entire image is quite dim; the edge characteristics like river edges are not very clear, the enhancement effect is not prominent. Regarding fusion image (4) (threshold value TH =1), in fact, this method degenerates the linear method of weighting; the spectral characteristic maintenance is insufficient; the resolution is not high. But regarding fusion image (5) (threshold value TH =0), the ringing effect appears obviously, to cause the thing texture fuzzy. But the fusion image (6) obtained in auto-adapted threshold value law proposed in the paper is much clearer than image (3), (4), (5), either in the region outline or in river boundary. Moreover the spectral characteristic also maintains well.

Method types		spectrum tortuosity	Correlation coefficient	
			SPOT Image	TM multi-spectral Image
Method	Wavelet J=1	19.4175	0.7278	0.7494
The new method	TH=1	20.1420	0.8097	0.748012
	TH=0	24.05	18.3711	0.7845
	Adaptive TH		0.8551	0.7969

Table 2 is parameter contrast of the image fusion result.

In order to objectively carry on the quality synthetic evaluation to this paper method and the traditional wavelet method, the two aspect appraisals of the imagery correlation coefficient and the spectrum tortuosity have been given.

Table 2 is parameter contrast of the image fusion result. It can be seen from the image parameter result provided in the table that the method of this paper all has a very good effect on both enhancing the spatial texture characteristic of the multi-spectrum image and maintaining the spectrum information.

5. CONCLUSION

The study of the weighting image fusion based on wavelet transformation, on the basis of studying the general weighing methods, proposes a new thought: different fusion rules will be used in low frequency image and high frequency image. The simple weighted average in low frequency uses; as for high frequency, according to the image statistical property, a fusion method, based on the biggest criterion of partial region standard deviation, is designed to carry on the processing . The experimental result has indicated the validity and the usability of this method.

The study of image fusion by combining the wavelet transformation with the feature of human vision system, on the basis of analysis the characteristic of vision contrast gradient, creates a kind of measure substitution block variance of measuring the image block uniformity. Then on this basis, a new fusion rule is proposed. It can be seen, from the fusion image and the quantification appraisal result, that a satisfactory fusion effect will be achieved by using the auto-adapted threshold value to carry on the dynamic fusion.

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