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Remote Sensing Image Fusion Based on the Combination Grey Absolute Correlation Degree and IHS Transform

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Abstract: An improved fusion algorithm for multi-source remote sensing images with high spatial resolution and multi-spectral capacity is proposed based on traditional IHS fusion and grey correlation analysis. Firstly, grey absolute correlation degree is used to discriminate non-edge pixels and edge pixels in high-spatial resolution images, by which the weight of intensity component is identified in order to combine it with high-spatial resolution image. Therefore, image fusion is achieved using IHS inverse transform. The proposed method is applied to ETM+ multi-spectral images and panchromatic image, and Quickbird's multi-spectral images and panchromatic image respectively. The experiments prove that the fusion method proposed in the paper can efficiently preserve spectral information of the original multi-spectral images while enhancing spatial resolution greatly. By comparison and analysis, the proposed fusion algorithm is better than traditional IHS fusion and fusion method based on grey correlation analysis and IHS transform. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Image fusion, Grey absolute correlation degree, Edge detection, IHS transform.

1. Introduction

In general, panchromatic image has a higher spatial resolution and a lower spectral resolution. On the contrary, multi-spectral images have a higher spectral resolution and a lower spatial resolution. The image fusion process between them makes fused image to possess not only higher spatial resolution of high-resolution image (e.g. panchromatic image), but also higher spectral resolution of multi-spectral image, and it improves interpretation precision, classification accuracy, multi-temporal monitoring capacity and the accuracy of plotting thematic map. Now, a lot of data fusion methods are developed: High Pass Filter (HPF), Brovery Transform (BT), Principal Component Analysis (PCA) transform, Wavelet Transform (WT), IHS transform and so on [1].

In the process of HIS transform, the first component is replaced by high-spatial resolution image directly, so that spectral distortion in comparison with original image will take place, which is harmful to correct recognition and classification. Many scholars have introduced the grey correlation analysis to HIS transform of image fusion, which can effectively overcome the spectrum distortion of IHS transform, good results would be achieved [2, 3]. In this paper, on the basis of the reference [4], after analyzing the disadvantages of the grey correlation degree and the superiority of grey absolute correlation degree, a new image fusion method is proposed. Not only are edge points and non-edge points in panchromatic image detected by using of the grey absolute correlation degree, but also image weighted fusion is conducted adopting IHS transform. Experiments show that the new method is better than another methods, which indicates traditional IHS transform and combination of grey relationship analysis and IHS transform (detailed information may refer to the reference [4]), the visual interpretation and qualitative assessment verify its effectiveness and reliability .

2. Edge Detection Based on Grey Correlation Analysis

The grey system theory was founded by Professor Julong Deng (Chinese scholar) in 1982, which focused on less data, deficient information, uncertainty problem [5]. Grey correlation analysis is an important part of grey system theory, which measures correlation degree by the geometric relationship or curve similarity, comparative analysis of curve or geometric relationship on the reference sequence and comparative sequence, if two curves are similar in shape, the correlation degree is larger, otherwise, smaller one.

2.1. Grey Correlation Calculation

Since the grey system theory was founded, many correlation calculation methods have been put forward subsequently [6]. Representative one is proposed by Prof. Deng, detailed processing may refer to reference [5], which is calculated as follows:

1) Determining the reference series $x_0(k)$ and compare series $x_i(k)$, where:

$$\begin{cases} k = 1,2,\cdots P, P \in \text{integer} \\ i = 1,2,\cdots N, N \in \text{integer} \end{cases}.$$

2) Calculating the grey correlation coefficient $r(x_0(k), x_i(k))$ between reference series $x_0(k)$ and compare series $x_i(k)$.

$$r(x_0(k), x_i(k)) = \frac{\Delta_{\min} + \rho \times \Delta_{\max}}{\Delta_{oi}(k) + \rho \times \Delta_{\max}}, \quad (1)$$

where:

$$\begin{cases} \Delta_{oi}(k) = \left| x_0(k) - x_i(k) \right| \\ \Delta_{\min} = \min_i \min_k \Delta_{oi}(k) \\ \Delta_{\max} = \max_i \max_k \Delta_{oi}(k) \end{cases}$$

ρ is the resolution coefficient and the constant (generally, $\rho = 0.5$, thus:

$$r(x_0(k), x_i(k)) \in (0,1].$$

3) Calculating the grey correlation degree between reference series $x_0(k)$ and compare series $x_i(k)$.

$$r(x_0, x_i) = \frac{1}{P} \sum_{k=1}^{P} r(x_0(k), x_i(k)), \quad (2)$$

The calculation of correlation degree is affected several aspects in the following: the influence about minimum absolute difference and maximum absolute difference of two levels; the correlation coefficient is affected by sample number of each point. Correlation coefficient, correlation degree is also affected by resolution ρ. Detailed analysis may view reference [6].

2.2. Grey Absolute Correlation Degree Calculation

In order to overcome the shortage of the above correlation degree, the concept of grey absolute correlation degree was put forward by Zhenguo Mei, and the corresponding calculation method was given out. The basic idea is that the correlation degree is determined by degree of closeness of rate of curve in the corresponding period of time according to two time series. For discrete data series, degree of closeness of two curves indicates proximity of rate of curve in the corresponding period of time about two time series, if the two curves on the slope of the curve at all times equal to or smaller difference, the correlation coefficient between them is large, otherwise small. Grey absolute correlation degree calculated as follows [7]:

1) Initializing the reference series and compare series, initialization is to make the series comparable.

$$\begin{cases} x_0(k) = x_0(k) / x_0(1) \\ x_i(k) = x_i(k) / x_i(1) \end{cases}, \quad (3)$$

2) Calculating correlation coefficient of each point.

$$r(x_0(k), x_i(k)) = \frac{1}{1 + \left| (x_0(k+1) - x_0(k)) - (x_i(k+1) - x_i(k)) \right|} \quad (4)$$

3) Calculating absolute correlation degree.

$$r(x_0, x_i) = \frac{1}{P-1} \sum_{k=1}^{P-1} r(x_0(k), x_i(k)), \quad (5)$$

Grey absolute correlation degree has two characteristics: symmetry and uniqueness. On the one hand, two series may be regarded as reference series to calculate correlation coefficient and correlation degree respectively, the value is consistent, and it is not affected by other factors, that is:

$$r(x_0(k), x_i(k)) = r(x_i(k), x_0(k))$$

On the other hand, when sample number changes, the correlation coefficient has no change, it has the property of uniqueness [5].

2.3. The Edge Detection Based on Grey Absolute Correlation Degree

The edge detection of gray system theory into practice is a novel idea, some scholars have carried out some studies on the application of image edge detection by using of Grey Relational Analysis.

The edge of image refers to the image of the pixel gray set, including step change or roof change. For edge detection, each pixel in an image belongs to either edge points or non-edge points. Theoretically, adjacent pixels near edge points have drastic change in the grey value; the grey absolute correlation degree reflects the change. Ideal non-edge points have the same value as adjacent pixels; therefore, reference series x_0 may be consisted of ideal non-edge points and its eight neighborhood pixels, correspondingly, compare series x_i is composed by one pixel in an image and its eight neighborhood pixels. Through grey correlation analysis, the value of grey correlation degree implies similarity between the reference series and compare series, when it is larger, the geometric shape of two series is similar, thus, the pixel can be thought of as non-edge point; in the same way, when it is small, the pixel is edge point [8].

Two deficiencies exist in edge detection applied by correlation degree of Prof. Deng, one is resolution ρ results in non-uniqueness of correlation degree, another is distance between two series affects correlation degree. Grey absolute correlation degree has five superiorities in edge detection (namely symmetry, correlation degree uniqueness, non-correlation with distance, operability, direction) [5]. In addition, the compare series in reference [4] only select five pixels, including one pixel and four neighborhood pixels located horizontal and vertical directions, so other pixels located in the diagonal direction are not considered, which leads to edge detection under restrictions in the direction. For these reasons, compare series consist of one pixel and eight neighborhood pixels, then edge detection is conducted by grey absolute correlation degree, complete steps are in the following [9]:

1) Determining the reference series and compare series.

Let reference series $x_0 = [1,1,1,1,1,1,1,1,1]$, comparative series:

$$x_i = [x_{i,j}, x_{i-1,j-1}, x_{i-1,j}, x_{i,j-1}, x_{i,j+1}, x_{i+1,j-1}, x_{i+1,j}, x_{i+1,j+1}],$$

where $i = 1,2,\cdots M; j = 1,2,\cdots N$, If $i = 0, j = 0$ or $i = M, j = N$, non-defined pixels of eight neighborhood have the same value as nearest pixels, thus compare series (size $M \times N$) will be obtained.

2) Calculating the correlation coefficient $r(x_0(k), x_i(k))$ between reference series and compare series.

3) Calculating absolute correlation degree and extracting the image edge. Judgment rule of edge points is: when $r(x_0, x_i)$ is greater than a given threshold value θ of correlation degree, the pixel is non-edge point because it has similar characteristic with reference series, otherwise, it is edge point.

Fig. 1 is edge detection results for TM image, which shows two methods of edge detection result difference is very big, in terms of the detail of the edge image, edge detection method based on grey absolute correlation degree is significantly better than Roberts algorithm.

(a) original TM image (b) edge detection by Roberts algorithm (c) edge detection by grey absolute correlation degree ($\theta = 0.85$)

Fig. 1. Results of edge detection to TM image.

3. Image Fusion Based on Grey Absolute Correlation Degree and IHS Transform

Considering the disadvantages of the IHS transform fusion method, this paper has an improvement on the basis of reference 4.

The grey correlation analysis based on grey absolute correlation degree is used to conduct edge detection of high-spatial resolution, and fused IHS and multi spectral data. The basic process is as follows:

1) Selecting three bands of multi-spectral remote sensing data for IHS transform, then, lightness (I), hue (H) and saturation (S) components are obtained.

2) Conducting edge detection for high-spatial resolution using the grey correlation analysis based on grey absolute correlation degree, edge points and non-edge points are gotten.

3) Carrying out histogram matching between high-spatial resolution image and the above lightness component I, obtaining a new similar image with lightness component histogram.

4) Linear weighted fusion is conducted between high-spatial resolution and lightness component I obtained by histogram matching. In order to highlight the details of high-spatial resolution image, larger weights are given the edge points, thus getting new lightness component I', repeated experiments show the weight for 0.75 and 0.25 respectively achieves a good fusion result.

$$I'[i,j] = \omega_1[i,j] \times P[i,j] + \omega_2[i,j] \times I[i,j], \quad (6)$$

If the high-spatial resolution image pixel $P[i,j]$ is edge points, that is, $r(x_0,x_i) \geq \theta$, then $\omega_1[i,j] = 0.75, \omega_2[i,j] = 0.25$. If the high-spatial resolution image pixel $P[i,j]$ is non-edge points, that is, $r(x_0,x_i) < \theta$, then $\omega_1[i,j] = 0.25$, $\omega_2[i,j] = 0.75$.

5) IHS inverse transform is carried out through new lightness component I', hue component (H) and saturation (S) component, therefore, the fused image is gotten.

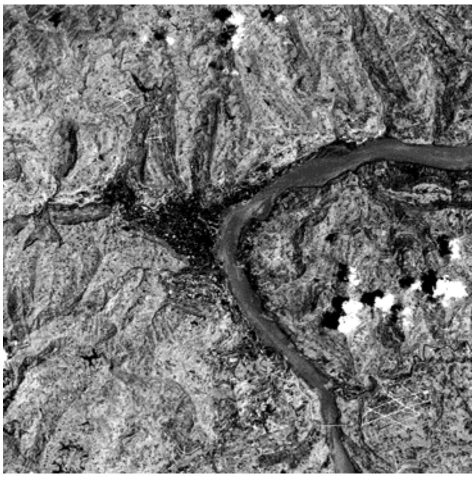
Because the grey absolute correlation degree in edge detection has many advantages, for example, detecting useful edge information accurately and effectively, good anti-noise performance [7]. As a result, the proposed new algorithm keeps not only the more high-spatial resolution image details information and the spectral information of multi-spectral remote sensing data, but also good anti-noise capacity.

4. Experiments and Analysis

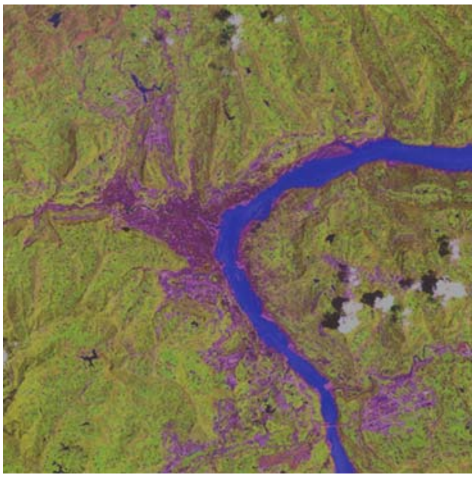
Experiment 1: ETM + multi-spectral and panchromatic image fusion.

We choose ETM + images of Wanzhou district Chongqing city, China, which is obtained on March 18th, 2008, image size is 1024×1024 pixels. There are two types of image for ETM+, multi-spectral images resolution is 30 meters, and high-resolution panchromatic band is 15 meters, as shown in Fig. 2, Fig. 2(a) and Fig. 2(b) are original images respectively vegetation, river, village, town and landslide can be discriminated clearly (see Fig. 2).

After each image radiation correction, image registration and re-sampling are carried out through image-to-image model, matching accuracy is controlled within 0.5 pixel, and then, other preprocessing is completed. Finally, fusion processing between ETM+ multi-spectral image and panchromatic image is conducted by three different methods that is, IHS transform, the method referred to reference [4], the proposed new method. The results may show in Fig. 3.

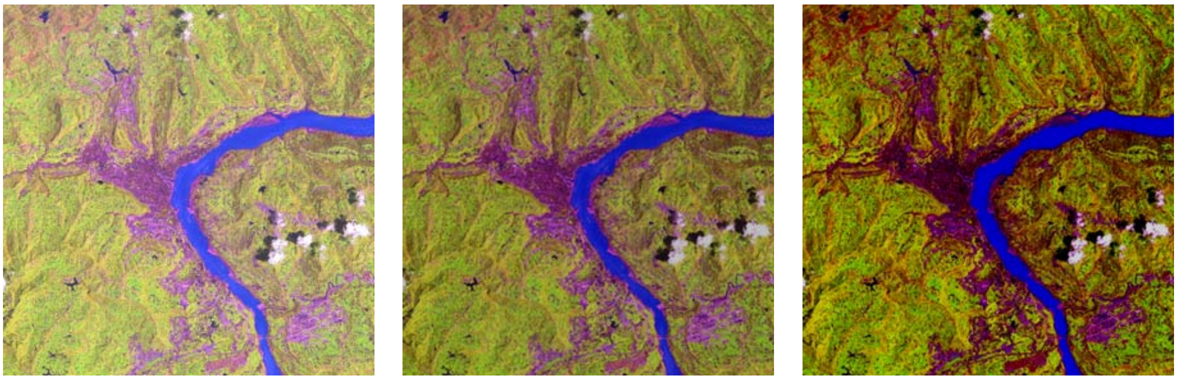


(a) Panchromatic image



(b) Composite image of TM3,4,5

Fig. 2. Original ETM+ image.



(a) *IHS* transform (b) Reference 4 method (c) Proposed method

Fig. 3. Comparison between different fusion results(TM 3,4,5 composite).

It is obvious in Fig. 3 that the texture and edge of image river, landslide, town in image Fig. 3(c) are clearly visible, compared with the original TM5,4,3 composite image, spatial resolution makes a remarkable improvement, and the tone is consistent, achieving good fusion effect. In addition, among the three methods, in Fig. 3(c), edge information is the most clear, spectral information is kept completely, the hue is brought into correspondence with original images, spectral deformation is small, visual effect is better than others.

So far, many quantitative assessment indexes of fusion result have been developed. This paper selects information entropy, average gradient, correlation coefficient and deviation index to assess the three fusion algorithm in spectrum fidelity, high frequency information fusion and image sharpness [10], the statistical indicators are shown in Table 1.

1) Entropy.

Image information entropy is an important index to measure the degree of image information increased. In general, if entropy is a greater, the image contains more abundant information [2]. From Table 1, the entropy of fusion image by the proposed method is 7.134, more than others, which shows that increased information is the most by the method.

2) Spectral fidelity.

The correlation coefficient between fused image and original multi-spectral image reflects their similarity, which indicates fused image keeps the spectral characteristics. Deviation index represents relative difference between the fused image and the original multi-spectral image average grey value, also reflecting deviation degree between the fused image and the original high spectral resolution images. From Table 1, compared with other methods, the deviation index of the proposed method is smallest, but the correlation coefficient is largest, which shows that the method can keep the original image spectrum information very good.

3) Image sharpness.

Average gradient reflects change property of small detail contrast and texture in an image, and also reflects the clarity of the image. From Table 1, the average gradient value of the proposed method is lowest, which is 5.637. It shows that sharpness of fused image by proposed method is highest, meeting the fusion demand.

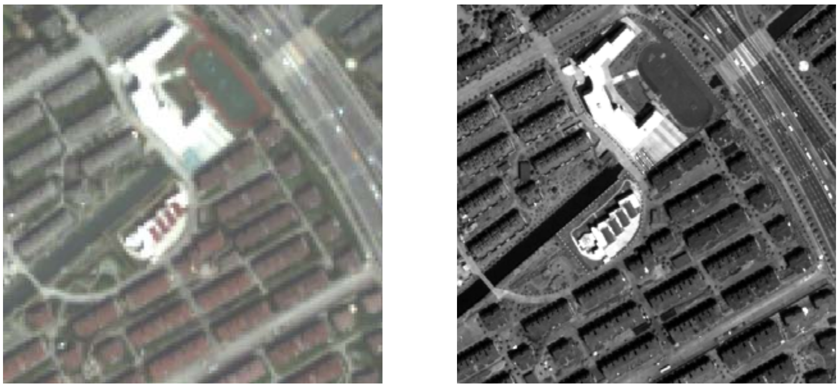
Comprehensive qualitative and quantitative analysis, the ETM + image fusion, the fusion algorithm in this paper in three kinds of fusion method can best to retain the original multi-spectral image spectral information, and space also get better enhance edge information details.

Table 1. Quantitative statistics of fused images from ETM+ data.

Method	Average gradient	Entropy	Deviation index	Correlation coefficient
Composite image	7.932	5.061		
IHS transform fusion	7.629	6.137	0.1246	0.7474
Reference [4] fusion	6.904	6.318	0.0746	0.8739
Proposed method	5.637	7.134	0.0575	0.9051

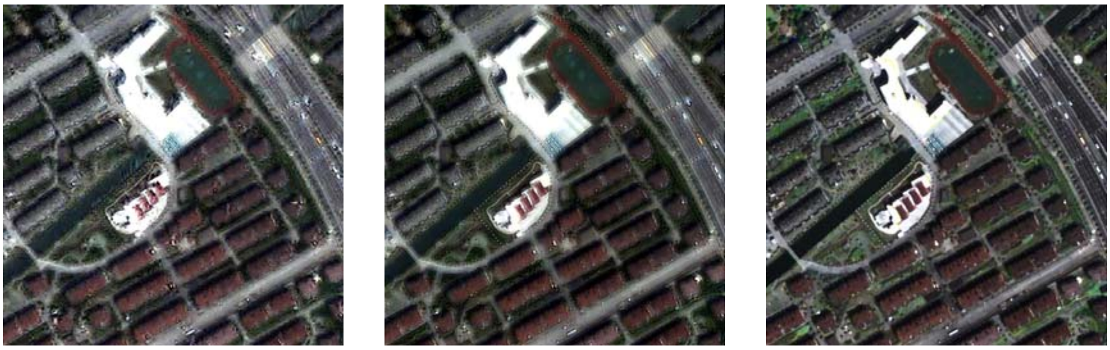
Experiment 2: Quickbird multi-spectral and panchromatic image fusion.

In order to verify this algorithm to other image fusion effect, Quickbird images of Xuzhou city in China (Fig. 4) are chosen for experiment, which were obtained on September 10th, 2011. Its panchromatic image resolution reaches 0.61 meters, multi-spectral image resolution is up to 2.44 meters, there are four bands in multi-spectral image, that is, red, green, blue and infrared. Image size of experimental area is 512 × 512 pixels, using the same fusion methods as experiment 1, the fusion result is shown in Fig. 5.



(a) Composite image (band red, green, blue) (b) Panchromatic image

Fig. 4. Original Quickbird images.



(a) *IHS* transform (b) Reference 4 method (c) Proposed method

Fig. 5. Comparison between different fusion results.

From the visual effect (see Fig. 5), by comparison, Fig. 5(c) image and original Quickbird multi-spectral image are consistent in hue, keeping the best spectral information, and *IHS* transform and reference 4 fusion methods keep the poorer spectral information. In the aspect of image edge, texture and clarity, the proposed method fusion image is the best, roads, river, vegetation, ground track field and buildings are clearly visible, many objects in Fig. 5(a) and Fig. 5(b) are indistinct, overall, the proposed method has good property of not only enhancing spatial detail edge information, but also keeping the best spectral fidelity. From quantitative analysis (see Table 2), compared with other methods, the proposed method has highest average gradient, largest entropy and correlation coefficient, these values are 17.037, 7.859 and 0.8446 respectively, which show that the fused image is the most clear, containing the most information, keeping the most spectral information, meanwhile, deviation index is smallest, which indicates fused image has high spatial resolution and spectral resolution, spectral distortion is small, so it is an ideal, effective and reliable new method.

Table 2. Quantitative statistics of fused images from Quickbird images.

Method	Average gradient	Entropy	Deviation index	Correlation coefficient
Composite image	9.078	5.245		
IHS transform fusion	13.216	6.868	0.2916	0.5123
Reference [4] fusion	15.596	7.226	0.1731	0.7304
Proposed method	17.037	7.859	0.1275	0.8446

5. Conclusions

This paper studies the combination of grey absolute correlation degree and IHS transform to realize multi-source remotely sensing imagery fusion, and carrying out the experimental analysis. Conclusions are drawn as follows:

1) Grey absolute correlation degree overcomes the shortcomings of correlation degree non-

uniqueness caused by discrimination coefficient ρ and correlation degree affected by distance between these series, which is useful to edge detection of remotely sensing imagery.

2) Using grey absolute correlation degree to extract edge information of high-spatial resolution image, image pixels are separated into edge points and non-edge points. When images are conducted weighted fusion by IHS transform method, edge points are given larger weight and non-edge points are given smaller weight, it is an effective method of multi-source remote sensing information fusion [11].

3) Two experiments show that the proposed method not only improves the spatial resolution of multi-spectral remote sensing image effectively, enhances the image sharpness, increases the amounts of information, integrates detail information of the high-spatial resolution image, but also has significant advantages in terms of keeping spectral information.

Despite the combination of the grey absolute correlation degree and IHS transform is a simple, effective method from the aspects of qualitative and quantitative analysis, there still are some problems to need further research, such as improvement is needed for image edge detection using grey absolute correlation degree in the area of smaller grey value, self-adaptive selection of correlation degree threshold θ, the combination of grey correlation analysis and other fusion methods, etc. [12]. In addition, fused image can be applied to subsequent processing such as image classification and information extraction, thus the accuracy and reliability of the remote sensing image processing and information extraction can be improved greatly.

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