3D WAVELET COMPRESSION TO MULTIPLE BAND REMOTE SENSING IMAGES BASED ON EDGE RESERVATION

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ABSTRACT:

In this paper, a practical quasi-lossless compression concept and corresponding compression ratio and quality requirements are proposed for the multiple band images database construction and web release application. The physical therapy of 3D wavelet analysis to the multiple band images data compression is discussed and the fast 3D wavelet transformation model and algorithm to the multiple band images is designed. The proposed algorithm is fully exploit the spectral and spatial correlation in the data. To adopt to the local edge characteristics of multispectrum image, the 3D wavelet multiple band images compression technique route is proposed based on the contour and edge feature of the multiple band images in the same region. And the remove correlation method of the multiple band images contour feature keeping using 3D wavelet analysis and relative quantification coding methods to different wavelet coefficient based on edge preservation is presented to code the multiple band images. The compression and reconstruction experiment results to the 16-band images of the imaging spectrum sensor and the 36-band MODIS images can obtain compression ratio over than 16 with PSNR to 42 and reach the quasi-lossless requirements, which show that this compression technique can improve the quality of reconstruction images to the requirement of quasi-lossless with the high compression ratio.

1. INTRODUCTION

In RS, GIS and DPS (digital photogrammetry system), one of key technique is how to deal with the real time transmitting of huge remote sensing data and how to build image database. And Building digital libraries has become white hot in this era of internet and the World Wide Web. In image databases, many images must be stored and retrieved, and in data communication applications, the image must be small enough to be transferred quickly. The loss less coding based on statistics has low compression ratio. Although the wavelet compression and fractal compression will reach a high compression ratio, they belong to degraded compression and need much more CPU time, which affect these methods actual application in the field of the remote sensing. The remote sensing images have higher spatial resolution in wider coverage areas, and a number of spectral bands, their accessibility is hindered by the size of images. To alleviate these limitations, the image data should be compressed.

The research of multiple spectrum images compression without lossless can just reach the ratio about 3:1 and it can be not used for the real applications(Zhang,1998). As one kind of sequence images, the multispectrum images have strong correlation among different frame or band. The researches of multispectrum image compression focus on lossless compression. The lossless compression of 224 bands AVIRIS images (Huffman, 1994) obtains the compression ratio of 1.33-1.50:1 and the 7 bands Landsat TM images reach 1.7-2.4:1. Memen,1994 propose the prediction tree for multispectrum image compression with the resumption of neighbour band image having the same prediction tree and then the prediction tree can be used to remove redundancy among different bands. All these compression method to multispectrum images are based on stastic and lossless and they can not reach high compression ratio to meet the real application.

The authors propose that exparty pursuing compression ratio and the quality of reconstruction images are not advisable. The quasi-lossless compression technique is the best way for the multiple spectrum images compression. What is called "quasi-lossless " is that the gray standard deviation of the homologous pixels between the original image and the restoration image after reconstruction is less than the quantified noise(Zhou,1999 and HU, 2001). At the same time, the accuracy of pixels must be less than the sensing imaging system's distortion. Thus, we can satisfy the high ratio compression and ensure not to loss the image information.

In this paper, a practical quasi-lossless compression concept and corresponding compression ratio and quality requirements are proposed for the multiple band images database construction and web release application. The physical therapy of 3D wavelet analysis to the multiple band images data compression is discussed and the fast 3D wavelet transformation model and algorithm to the multiple band images is designed. The proposed algorithm is fully exploit the spectral and spatial correlation in the data. To adopt to the local edge characteristics of multispectral image, the 3D wavelet multiple band images compression technique route is proposed based on the contour and edge feature of the multiple band images in the same region. And the remove correlation method of the multiple band images contour feature keeping using 3D wavelet analysis and relative quantification coding methods to different wavelet coefficient based on edge preservation is presented to code the multiple band images. The compression and reconstruction experiment results to the 16-band images of the imaging spectrum sensor and the 36-band MODIS images can obtain compression ratio over than 16 with PSNR to 42 and reach the quasi-lossless requirements, which show that this compression technique can improve the quality of reconstruction images to the requirement of quasi-lossless with the high compression ratio.

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2. METHODOLOGY

2.1 Data Analyse

Three types sensor multispectrum images are discussed in this paper for compression experiment. Table 1 gives the multispectrum images information.

Table 1 Test Images

Image Name	Sensor	Experiment Band	Resolution	Area	Image Size(Pixel)
TM	Landsat	5*	20m	Suburb of Wuhan	512×512
E	Imaging Spectrum Instrument	16	100m	Qinian Mountainous Area	480×480
TDF	MODIS	34	200m	South China	1354×4670

*TM has 7 bands, while the correlation between band 1 and 2 is too high and the resolution of band 6 is not same to others band, we omit band 2 and 6.In fact only 5 bands is in use and we number them T1, T2, T3, T4, T5 in turn.

Table 2 Multispectrum Images Correlation Analyse Results

Sensor Type	Band Number	Reference Image	Correlation Coefficient	Average
LandSat TM	5	3	0.855/0.983 /0.950/0.974	0.941
Imaging Spectrum Instrument	16	16	0.939/0.940/0.942/0.943/0.944/ 0.945/0.947/0.948/0.949/0.95/ 0.95/0.95/0.95/0.95/0.95	0.946
MODIS	34	14	0.962/0.956/0.960/0.960/0.965/0.970/0.975/0.980/ 0.985/0.990/0.995/1.000/0.995/0.990/0.990/0.992/ 0.995/0.999/0.998/0.996/0.992/0.989/0.986/0.985/ 0.983/0.981/0.9790.977/0.974/0.974/0.975/0.976/0.975	0.981

2.2 Correlation Analyse of Multispectrum Images

The compression technique of multispectrum images is an urgent problem for the remote sensing image storage, image database and transmission. All the compression technique is realized through remove data redundancy from the Shannon entropy. Different kinds of images have the different redundancy characteristic. The multispectrum have two kind of redundancy: spatial redundancy and spectrum redundancy . The spatial redundancy presents the correlation of the neignbor pixels in some specific band which is simular to single band remote sensing image and the compression can be realized through general compression algorithms such as JPEG2000. The spectrum redundancy including the statistic redundancy and structure redundancy . Thus, the multispectrum images compression focus on both the pixel correlation between neighbour pixels and edge structure of some object in different band images.

There are various compression methods for spatial decorrelation(Jain, 1991), relatively few studies for spectral decorrelation across bands have been presented. Saghri,1995 use Karhunen-Loeve transform (KLT), which is theoretically the optimum method to spectrally decorrelate the image data.
Comparing to the common single band remote sensing image, the character of the spatial correlation among the multispectrum images is the mode localization. The multispectrum images are a group of images to the same region in different bands. Each band has an image while the imaging objects are the same. HIRIS has 192 bands thus there are corresponding 192 images of the same objects. Although the pixels of the same object have some difference, there are presenting the same object and have the same geometric feature such as the edge and structure., which mean the strong correlation. And these band redundancy is determined by the resolution of speactrum. High spectrum resolution has higher spectrum redundancy .

Table 2 is the spectrum correlation among the 5 band Landsat images, 34 bands MODIS image and 16 bands imaging spectrum sensor images.

As table 2 shown, the band image correlation of the same region is near 95%, which means there are strong spectrum correlation among the multispectrum remote sensing and these spectrum correlation redundancy will be higher as the band increases. And the compression algorithm proposed in this paper mainly focus on this spectrum redundancy .

2.3 Multi-band Wavelet Analyse

Wavelet transform is always used in the image compression. After wavelet transformation, the image is divided into different presentation. Thus, the different quantification policy is design to the wavelet coefficient to obtain compression. While, the 2D wavelet are indeed well-suited to present smooth and textured region of images, the 2D wavelet description of edges are high inefficient in some specific scale. The multi-band wavelet can express edge or object geometric feature more accurately. This can be used for edge reserved compression to obtain high reconstruct image quality. In this paper, the 3D wavelet transformation is adopt as the multi-band wavelet analyse to obtain much precise edge. Following is the 3D wavelet transformation analyse.

(1) Multiple scale analyse

The multiple scale analyse of spatial domain $L^2(R)$ refers to the spatial list $\{Vm\}_{m\in Z}$, which fulfil the following conditions:

①Consistent monotony

$$\cdots \subset V_{-1} \subset V_0 \subset V_1 \subset \cdots \quad (1)$$

②Gradually perfectibility

$$\bigcap_{m\in Z} = \{0\}, \overline{\bigcup_{m\in Z} V_m} = L^2(R) \quad (2)$$

③Regulation of flex

$$f(x) \in V_m \Leftrightarrow f(2x) \in V_{m+1}, \forall m \in Z \quad (3)$$

④ Existency of Riesze base: there is $\varphi \in V_0$, $\{\varphi(x-n)\}, n \in Z$ as theRiesze base of V_0 . And $\varphi \in V_0$ can meet the following condition:

$$V_0 = \overline{span\{\varphi(x-n)\}, n \in Z} \quad (4)$$

Thus, there is $0 \prec A_1 \le A_2 \prec \infty$, which can obtain the following arbitrary relation to $(C_n)_{n\in Z} \in l^2(Z)$:

$$A_1 \sum_{n\in Z} |C_n|^2 \le \left\| \sum_{n\in Z} C_n \varphi(x-n) \right\| \le A_2 \sum_{n\in Z} |C_n|^2 \quad (5)$$

where $l^2(Z)$ presents the square summary of total list, that is:

$$l^2(Z) = \left\{ (a_l)_{l\in Z}, \sum_{l=-\infty}^{\infty} |a_l| \prec \infty \right\} \quad (6)$$

(2) Construction of Multi-band wavelet

As the multi-scale analyse, the scale function with interposition property can be constructed and corresponding conjugated filtering of M-band as the following equation:

$$H(z) = \left[\frac{l - z^M}{M^{1/2}(1-z)} \right]^2 \left(\frac{l+\theta}{2} + \frac{l-\theta}{2}\right), \left(\theta = \sqrt{\frac{2M^2+1}{3}}\right) \quad (7)$$

Thus, the wavelet coefficient can be obtained through the above equation.

(3) Image multi-band decompose and reconstruct

As the above scale function and the , we can obtain the image wavelet decomposition and reconstruction algorithm.

Taken image as $\{a_{o,n_1,n_2}\}$, the wavelet decomposition formula of M-band wavelet can be expressed as following:

$$a_{j+1,k,l} = \sum_{n_1}\sum_{n_2} c_{n_1-Mk} c_{n_2-Ml} a_{j,n_1,n_2} \quad (8)$$

$$b^{s_1,s_2}_{j+k,k,l} = \begin{cases} \sum_{n_1}\sum_{n_2} c_{n_1-Mk} d^{s_2}_{n_2-Ml} a_{j,n_1,n_2}, s_1 = 0, l \le s_2 \le M-1 \\ \sum_{n_1}\sum_{n_2} c_{n_2-Mk} d^{s_2}_{n_2-Ml} a_{j,n_1,n_2}, s_2 = 0, l \le s_1 \le M-1 \\ \sum_{n_1}\sum_{n_2} c_{n_1-Mk} d^{s_2}_{n_2-Ml} a_{j,n_2 n_1}, s_1 = 0, l \le s_2 \le M-1 \end{cases} \quad (9)$$

The corresponding image reconstruct to the M-band wavelet can be expressed as:

$$a_{j,k,l} = \sum_{n_1}\sum_{n_2} c_{k-Mn_1} c_{l-Mn_2} a_{j+l,k,l} + \sum_{s_1,s_2=0,s_1+s_2=0}^{M-1} \sum_{n_1}\sum_{n_2} d^{s_1}_{k-Mn_1} d^{s_2}_{k-Mn_2} b^{s_1,s_2}_{j+l,k,l} = \sum_{n_1}\sum_{n_2} (c_{k-Mn_1} c_{l-Mn_2} a_{j+l,k,l} + \sum_{s_1,s_2=0,s_1+s_2=0}^{M-1} d^{s_1}_{k-Mn_1} d^{s_2}_{k-Mn_2} b^{s_1,s_2}_{j+l,k,l}) \quad (10)$$

2.3 Edge Reservation based Quantification Algorithm in Multi-band Wavelet Domain

After multi-band wavelet transformation, the images are divided into different parts. The compression based on wavelet generally adopt different quantification methods to different wavelet coefficient. The 2D wavelet transformation can obtain the edge image while the edge image size is one of 2^k of the original image size. The multi-band wavelet can obtain edge image with arbitrary size and can well keep the image structure and edge feature. Figure 1 is the low frequency edge coefficient images of 3D wavelet decomposition.

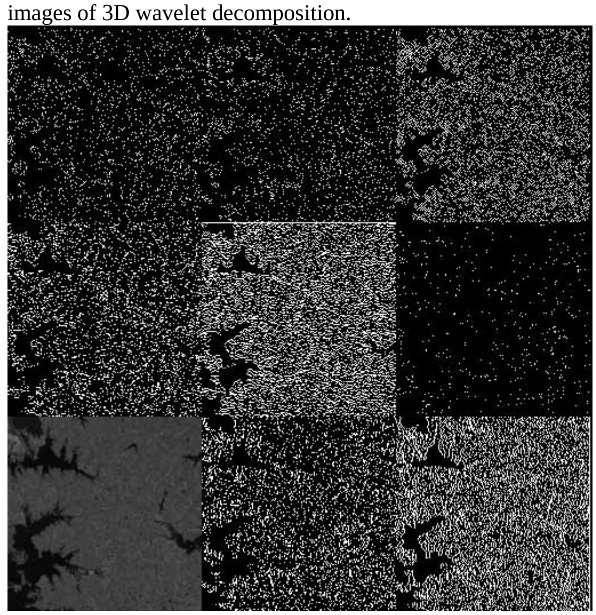

Figure 1 3D Wavelet Decomposition

The general quantification of the high frequency wavelet coefficient is the same. As figure shown, the high frequency coefficient of multispectrum image after wavelet transformation preserves the texture structure and edge feature in different directions. If the coefficient present the edge, the wavelet coefficient is high. And the plain region in the image has low wavelet coefficient. In order to keep the object edge and contour, the quantification of wavelet coefficient with edge and contour should adopt high and precise level while the plain region can be quantize with coarse level. In this paper, the wavelet coefficient quantification is done after the edge extraction. Hence the edge is detected from the high frequency wavelet coefficient, the left wavelet coefficient can be quantized with much coarse level to obtain higher compression. Figure 2 gives the quantification policy of the wavelet coefficient based on the edge reservation:

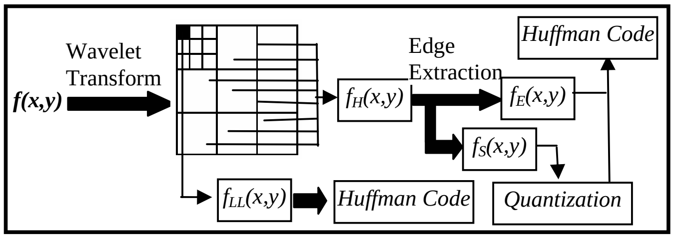

Figure 2 Wavelet Coefficient Quantization Flow

Where ***f(x,y)*** is the original image. $f_{LL}(x,y)$ is the low frequency coefficient image. $f_H(x,y)$ is the high frequency coefficient. $f_E(x,y)$
is the edge image. $f_S(x,y)$is the left wavelet coefficient without edge.

In this paper, the sobel operator(as equation shown) is adopt to extract edge from the wavelet coefficient.

$$\begin{bmatrix} -1 & 0 & -1 \\ -2 & 0 & -2 \\ -1 & 0 & -1 \end{bmatrix} \quad \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Figure 3 show the edge detection result from the wavelet coefficient.

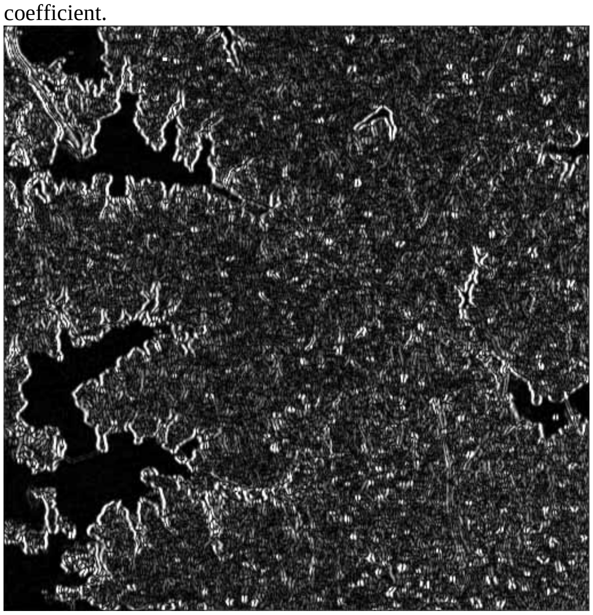

Figure3 Edge Extraction Result With Sobel Operator

Minus the edge coefficient from the wavelet coefficient, we can obtain the wavelet coefficient image without edge.

2.4 Technique flowchart of Multi-band wavelet based multispectrum image compression

After the 3D wavelet transformation, the multispectrum images can obtain high frequency wavelet coefficient image. As the above section analyse, the edge and contour can be extracted from the wavelet coefficient. For each spectrum image, the edge and contour is almost the same for they present the same region. Thus, the edge image extracted from the wavelet coefficient is a big redundancy among the multispectrum images. Only one edge image is kept to obtain high compression ration during the multispectrum image compression course.

Figure 4 give the multipsectrum images compression flowchart based on 3D wavelet transformation.

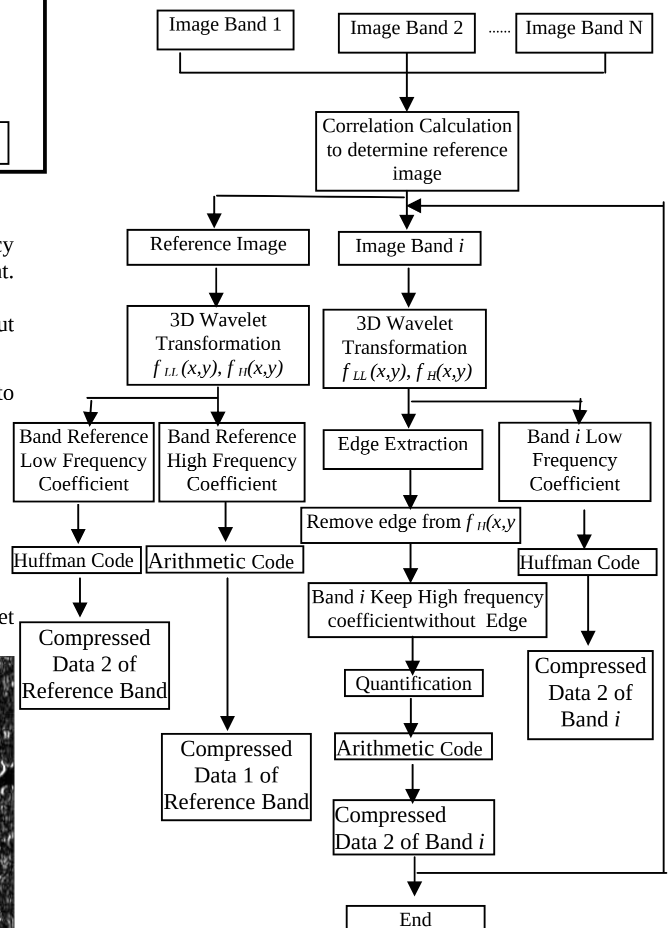

Figure 4 Compression Technqiue Flow of Multispectrum Images

As figure 4 shown, The multispectrum image compression technqiue is summarized as the following steps:

(1) Determining the reference image

How to determine the reference image is very important to the multispectrum image compression with high compression ratio and high reconstruction image quality. In this paper, the reference image is determined through the correlation analyse. Each spectrum image is selected to calculate the correlation coefficient to any other spectrum image. The spectrum image with the maximize average correlation coefficient is determined as the reference image. The reference image determination course can be explained as:

```
For i =1 to M
{
   For j =1 to M
   {
      If i!=j Cor(i,j) = CalCor(Image(i), Image(j))
   }
    AverCor(I,j) = Avreage(Cor(i,j))
   If (Max(AverCor(I,j)))
```

Ref = i

}

(2) Compression to the reference image

At first, the 3D wavelet transformation is done to the reference image. The lossless compression is adopt to the low frequency wavelet coefficient. And the arithmetic coding is taken to compress the high frequency wavelet coefficient.

(3) Compression to the *i* spectrum image

Decompose the *i* spectrum image using the 3D wavelet transformation. The lossless huffman coding is adopted to the low frequency image part. Then edge is extracted from the high wavelet coefficient image and be compression using Huffman coding. Remove the edge image from the high frequency wavelet coefficient image, the left wavelet coefficient is quantification with the specific level. In this paper, 4 level is taken to quantized the left wavelet coefficient. Finally, the arithmetic coding is done to the quantification wavelet coefficient image.

(4) Repeat (3) till all the multispectrum images are compressed.

The corresponding compression images reconstruct flow chat is illustrated as the figure5 :

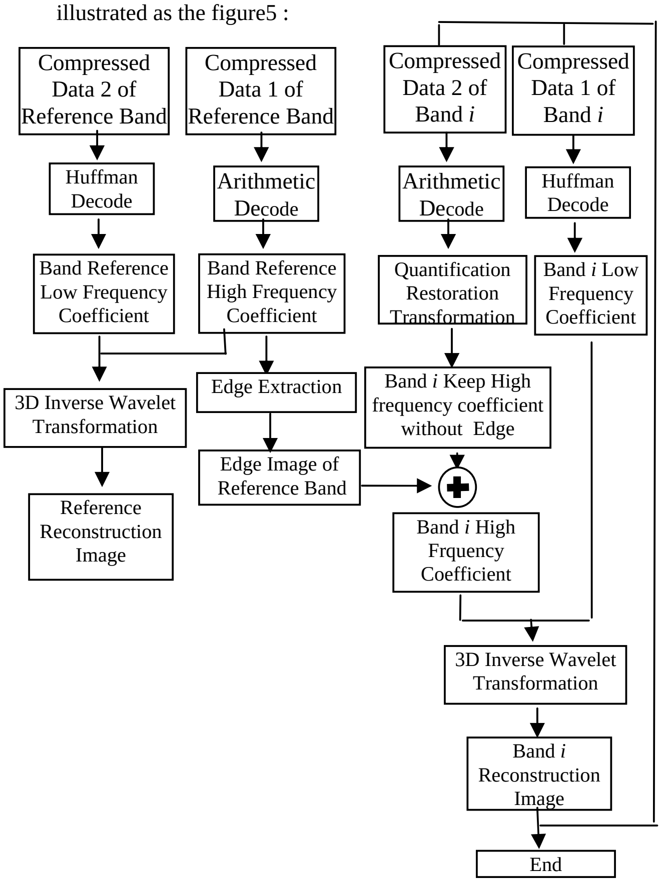

Figure 5 Reconstrunction Technique Flow

3. EXPERIMENTS AND RESULTS

Fidility and peak signal noise ratio(PSNR) are taken as the quality assessment parameters of the reconstruct image.

$$FIDELITY = \sum_{j=1}^{n} g_j g_j' / \sum_{j=1}^{n} g_j g_j \cdot \quad (11)$$

$$PSNR = 10\lg\left(\frac{255}{\delta}\right)^2 = 48 - 20\lg\delta \quad (12)$$

where g_j is the pixel grey value of original image.

g_j' is the pixel grey value of the reconstruct image.

n is the pixel number of image

δ is the standard deviation and can be calculated as following equation.

$$\delta = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(g_j - g_j'\right)^2} \qquad (13)$$

Fidelity is the geometry distortion of the reconstruction image comparing to the original image. PSNR (peak signal noise ratio) is the radiation distortion of the reconstruction comparing to the original image. Obviously, if the image has no loss, the fidelity is 1.0 and PSNR is infinity（expressed as δ =0, δ is the gray standard deviation of the homologous pixels between the original image and the decode image）. If δ equals 1.0, PSNR is 48. If δ equals 2.0, PSNR is 42. The quality request of the quassi-lossless compression comes from the standard deviation above 2.0, which ensure not to affect the application.

Table 3 and Table 4 show the compression result of the test images using the proposed method in this paper with reference image.

Table 3 Compression Result Using Low Correlation Reference Image

Image Name	Reference Band	Average Correlation	Total Compression Ratio	Reconstruction Images Quality
TM	2	0.626	12.32	0.9901/41.36
E	2	0.735	13.15	0.9897/41.86
MODIS	11	0.32	11.57	0.9756/40.91

Table 4 Compression Result Using High Correlation Reference

Image Name	Reference Band	Average Correlation	Total Compressio n Ratio	Reconstruction Images Quality
TM	3	0.941	17.42	0.9992/46.11
E	16	0.946	16.78	0.9984/44.52
MODIS	3	0.981	18.54	0.9987/42.87

As table 3 and table 4 shown, the multispectrum images compression quality are based on the reference image selection. The maximize correlation spectrum images have the biggest redundancy . Thus, compression can obtain high compression together with high reconstruction image quality.

4. CONCLUSIONS AND DISCUSSIONS

The 3D wavelet is a multi-band wavelet analyse and it can obtain edge and structure feature with higher accuracy, which is very use for image compression to obtain high reconstruct image quality. In this paper, the 3D wavelet transformation is proposed for the edge reservation image compression. The experiments of three typical multispectrum sensor obtain over than 16 compression ratio. The reconstruct image quality can meet the quassi-lossless requirement. It can be use for the image database buiding and image transmitting. The further improvements of the proposed method can be summarized as followings:

(1) Edge extraction algorithm: to obtain high precision edge and structure feature of the objects in the multispectrum image

(2) Quantification poly to wavelet coefficient

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