

Wavelet Compression Experiments of the Remotely Sensed Images for Three Kinds of Wavelet Families

Jin, Hong Sung* · Han, Dong Yeob**

ABSTRACT

A method to find the nearly optimal PSNR values for compression was tried to remotely sensed images. There is no rule to find the best wavelet pairs for image processing. The expected wavelet pairs following the suggested algorithm showed the optimal result for various kinds of images. Firstly, the PSNR variations with three wavelet families were analyzed. In many cases the longer wavelet filter shows the higher PSNR value, but the rate is getting less in orthogonal wavelet families. Wavelets with moderate filter length are suggested at the point of computational cost. For biorthogonal families it was hard to predict from the length of filters. Multiresolution wavelet analysis was used up to level 3 with three kinds of wavelet families. Biorthogonal wavelet family showed irregular pattern to get the maximum PSNR values, while orthogonal wavelet families showed regular pattern. In orthogonal wavelet families the nearly optimal wavelet pair can be predicted from the level 1.

Keywords : Wavelet, Compression, Remotely Sensed Images

요 약

원격탐사 영상에서 압축을 위한 근최적의 PSNR 값을 찾는 방법을 연구하였다. 예상 웨이블릿쌍은 다양한 영상에서 최적의 결과로 나타났다. 영상처리를 위한 최고의 웨이블릿쌍을 찾는 규칙은 없다. 제시된 알고리즘에 따라 예상 웨이블릿쌍이 다양한 종류의 영상에서 최적의 결과를 나타냈다. 먼저 세 개의 웨이블릿 패밀리에서 PSNR 값의 변화를 분석하였다. 직교 웨이블릿 패밀리에서는 많은 경우에 웨이블릿 필터의 길이가 길수록 높은 PSNR 값을 나타내지만, 그 증가 비율이 점차로 작아졌다. 연산비용의 측면에서 중간 필터길이의 웨이블릿을 제안한다. 쌍직교 웨이블릿 패밀리에서는 필터의 길이와 PSNR값의 관계를 예측하기는 어려웠다. 다차원 웨이블릿 분석에서는 세 개의 웨이블릿 패밀리가 3단계까지 처리되었다. 쌍직교 웨이블릿 패밀리는 최대 PSNR 값에서 불규칙한 패턴을 보였지만, 직교 웨이블릿 패밀리는 규칙적 패턴을 나타냈다. 직교 웨이블릿 패밀리는 1단계 결과로부터 근최적의 웨이블릿쌍을 예상할 수 있었다.

주요어 : 웨이블릿, 압축, 원격탐사 영상

* Associate Professor, Department of Applied Mathematics, The Chonnam National University (hjin@chonnam.ac.kr)

** Corresponding Author, Assistant Professor, Department of Civil & Environmental Engineering, The Chonnam National University (hozilla@chonnam.ac.kr)

1. Introduction

Wavelet-based image compression methods such as ECW (Enhanced Compression Wavelet), JPEG2000, MrSiD Multi-resolution Seamless Image Database) are used for airphoto, satellite images. In DWT Discrete Wavelet Transform), biorthogonal 9/7, 5/3, Daubechies D4 filter, asymmetrical filters, etc are used Chae et al., 2003).

There are too many wavelets to pick the best one for each applications. The theoretical criterions to pick the good wavelet were mentioned in some references (Daubechies, 1992, and Mallat, 1998). But for the real world it is impossible to pick the optimal wavelets.

In this research, we compared wavelet families and evaluated different horizontal and vertical filter pairs for compression. This method does not always give the algorithm to pick the optimal one for any cases but shows the nearly optimal wavelet pairs for remotely sensed image compression. It can be also used to other image processing fields.

The image processing method using wavelet transform divide the image to four frequency bands, i.e. LL LH HL HH, two channel band for horizontal and two for vertical direction. The energy distribution pattern to four parts depends on the kind of wavelet. The energy concentration of LL part was expressed by PSNR value. The peak signal-to-noise ratio, abbreviated PSNR, represents the ratio between the maximum possible power of a signal and the power of noise. Since the part concerned was LL, the other parts, LH, HL, and HH were treated as noise.

The PSNR values are calculated as follows:

$$psnr = 10 \cdot \log_{10} \left(\frac{\max^2}{mse} \right) ,$$

where

$$mse = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} \|M^0(i, j) - LL(i, j)\|^2$$

In the above equation, *mse* represents the mean squared error for m by the n monochrome original image, M^0 , and LL subimage. \max is the maximum possible pixel value of the image (Thomos et al., 2006).

In the experiment 1, the maximum PSNR values were found for eight kinds of remotely sensed images. A method suggested in Jin et al. (2009) was tried to these images. Then the results were compared to the real maximum PSNR values. The wavelets were used in vertical and horizontal direction separately. If n kinds of wavelet comes from a wavelet filter bank then n^2 wavelet pairs can be made for image processing filter.

In experiment 2 the PSNR values were calculated and compared with different filter length for three kinds of wavelet families. In experiment 3 the maximum PSNR values up to level 3 were calculated using the method in experiment 1. Then the wavelet pairs making maximum PSNR values were examined. As level goes up we can get more compressed images in a lossless image processing with perfect reconstructible wavelet bases. However we may lose important information as level goes up. Hence the experiment goes up to level 3.

2. Experiment 1: The choice of nearly optimal wavelet basis

For image compression optimal wavelet bases shows few non-zero coefficients in data processing. To find those wavelets we would better check the regularity of data and the vanishing moment of wavelets. The support of wavelets is another factor to consider. If a wavelet has p vanishing moment then its support is at least of size $2p-1$. Daubechies wavelets with p vanishing moment have the support size $2p-1$ while coiflet wavelets have the support size $3p-1$ (Daubechies, 1992). The vanishing moment and the size of biorthogonal wavelets depend on the filter length of analysis and synthesis. As an example db2 has 2 vanishing moment with the support size 3. If the image is very regular, wavelets with many vanishing moment is more efficient. Hence wavelets with longer filter length are good for regular images. If there are many singularities

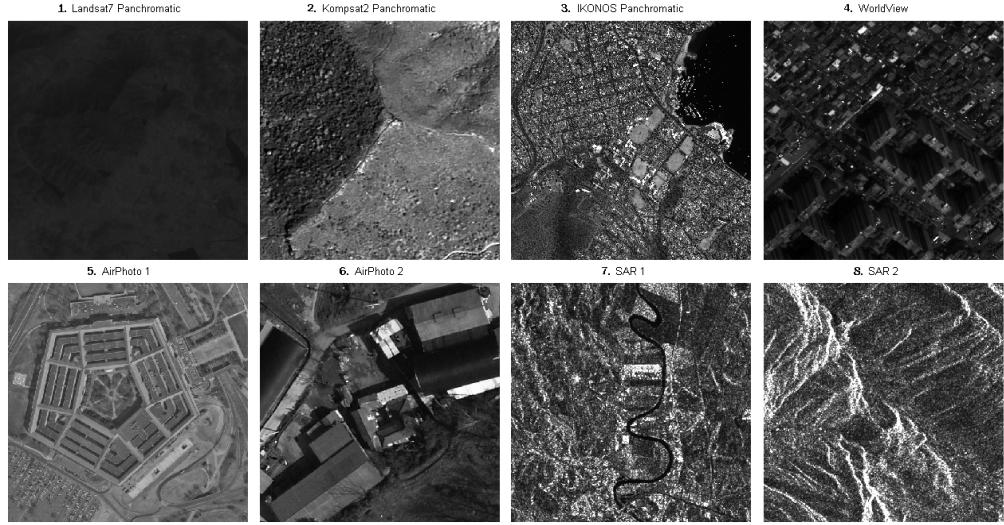


Figure 1. Remotely sensed images

in the image we'd better choose short length wavelets (Mallat, 1998).

But the regularity of the image is hard to count for real images. In fact it is almost impossible to find the optimal algorithm working everywhere. By heuristic, one method was suggested in Jin et al. (2009).

The method was tried for eight remotely sensed images which were selected because of various ground resolution, land use, optical and microwave images. The images are shown in Fig. 1. They are consisted of Landsat 7, Kompsat 2, IKONOS, WorldView, airphoto, synthetic aperture radar images.

The method is consisted of two steps. At first, fix the horizontal wavelet filter as db1 with various wavelets as vertical filter then pick the vertical wavelet which shows the maximum PSNR value. Second, change the role of horizontal filter to the vertical one. As an example if we have a filter bank consisted of {db1, db2, db4}. Then there could be 9 kinds of wavelet pairs. The wavelet pair {db(hmax), db(vmax)} is suggested which satisfies the following condition :

- (i) $\{db1, db(vmax)\} \geq \{db1, db^*\}$
- (ii) $\{db(hmax), db1\} \geq \{db^*, db1\}$

This algorithm is tested to the eight kinds of remotely

sensed images with 18 kinds of wavelet filter bank. Table 1 shows the wavelets used in experiment 1.

The expected wavelet pairs come from the above algorithm. Table 2 shows the results. For all images the expected wavelet pairs making maximum PSNR values are coincide with the real maximum ones. This may not work everywhere. However, this method may work good for many images without counting the regularities of images.

3. Experiment 2: Pattern of PSNR values for the three kinds of wavelet families

In multiresolution wavelet analysis the LL part is used as an target image to process in the next level. Hence the energy amount in the LL part is very important. The energy distribution to LL can be estimated through PSNR value. The PSNR value may depend on the kinds of wavelet filters. For different wavelet family the PSNR value variation may show different pattern.

Three types of wavelet families such as daubechies, coiflet, and biorthogonal wavelet families were chosen to this experiment. Compactly supported wavelets are guaranteed to have perfect reconstruction. Daubechies orthogonal wavelet family and biorthogonal wavelet family are

Table 1. Wavelets and their abbreviation used in experiment 1

wavelets	abbreviation
daubechies#	db1,db2,db4,db8,db10
symmlet#	sym2,sym4,sym8
coiflet#	coif1,coif3,coif4,coif5
biorthogonal#	bior2.6, bior3.1, bior3.5, bior3.9, bior4.4, bior6.8

Table 2. expected and real PSNR values for eight images

image#	wavelet pair (horizontal, vertical)		optimal/ nearly optimal
	expected max PSNR	real max PSNR	
1	(db10,coif5)	(db10,coif5)	optimal
2	(db10,coif5)	(db10,coif5)	optimal
3	(db10,db10)	(db10,db10)	optimal
4	(coif5,coif5)	(coif5,coif5)	optimal
5	(coif5,db10)	(coif5,db10)	optimal
6	(db8,db8)	(db8,db8)	optimal
7	(coif5,db10)	(coif5,db10)	optimal
8	(coif5,coif5)	(coif5,coif5)	optimal

widely used compactly supported wavelet groups. The coiflet is very similar to the daubchies wavelet families except the length of support of the scaling function. So three wavelet families are representative to the compactly supported wavelets.

To see the pattern of PSNR value variation the horizontal and the vertical filter were chosen identical filter. In each families the wavelets chosen were different with those in the experiment 1.

Table 3 shows the wavelet families and wavelets used in experiment 2 and 3. Wavelets in each families were numbered 1 to 5.

All those families are compactly supported wavelets. To construct the wavelet with perfect reconstruction the analysis and the corresponding synthesis filter, the alias cancellation and the distortion correction should be done to make a product filter. This product filter can be factored to make a analysis and synthesis wavelet pairs. The bio-

Table 3. wavelet families and numbering

# families \ #	1	2	3	4	5
daubechies	db1	db5	db8	db11	db14
coiflet	coif1	coif2	coif3	coif4	coif5
biorthogonal	bior2.8	bior3.5	bior3.9	bior5.5	bior6.8

Table 4. PSNR values for various wavelets in biorthogonal families

image	bior2.8	bior3.5	bior3.9	bior5.5	bior6.8
1	46.556	46.815	46.859	46.834	46.900
2	32.473	34.441	34.528	35.174	35.034
3	18.406	18.523	18.564	18.514	18.565
4	32.049	32.983	33.059	33.228	33.309
5	29.598	29.880	29.938	29.908	29.969
6	33.415	33.406	33.487	34.993	34.751
7	22.056	22.505	22.575	22.556	22.621
8	22.614	23.032	23.104	23.076	23.191

rthogonal and the daubechies families come from the factoring the product filter (Strang and Nguyen, 1996).

$$P_0 = F_0 H_0$$

where P_0 : product filter,

H_0 : lowpass filter for analysis,

F_0 : lowpass filter for synthesis

The coiflet wavelet come from the daubechies wavelet by modifying the scaling function (Daubechies, 1992).

3.1 Results for biorthogonal wavelet family

Table 4 shows the PSNR values for each eight remotely sensed images with biorthogonal wavelets. There are four patterns (as) shown in Fig. 2. Fig. 2(a) shows the pattern for the image 2. and 2(b) for the image 4. The pattern of PSNR for the images 1,3,7,8 follows the pattern of the image 5 shown in Fig. 2(c).

Without bior5.5 they show very similar pattern for all images except for the image 15. Bior5.5 and bior6.8 show

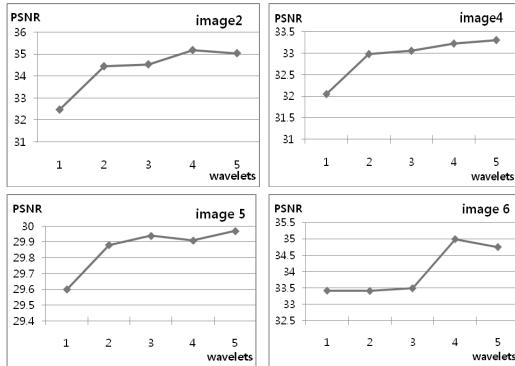


Figure 2. 4 patterns of PSNR variation for the biorthogonal family

Table 5. PSNR values for various wavelets in daubechies families

images	db1	db5	db8	db11	db14
1	45.338	46.819	46.894	46.952	46.963
2	28.417	34.114	35.159	35.633	35.843
3	18.060	18.540	18.561	18.613	18.594
4	29.086	32.884	33.321	33.507	33.640
5	28.429	29.883	29.989	30.040	30.045
6	32.467	33.679	36.020	34.418	35.662
7	20.820	22.470	22.611	22.765	22.759
8	21.316	23.019	23.159	23.296	23.330

high PSNR values for all the images. For the image 15, bior2.8 bior3.5 bior3.9 show relatively low PSNR values. Biorthogonal wavelet filtering depends on the filter length of analysis and synthesis. This family wavelets are hard to predict the result from the filter length. Biorthogonal 3.9 means that the filter length of analysis is 3 and that of synthesis is 9.

3.2 Result for daubechies wavelet family

Table 5 shows the PSNR values for each eight remotely sensed images with daubechies wavelets. Fig. 2 shows the pattern of PSNR variation with wavelets in daubechies family. The patterns for images 1,2,4, and 8 are similar to that of the image 5 in Fig. 3(a)

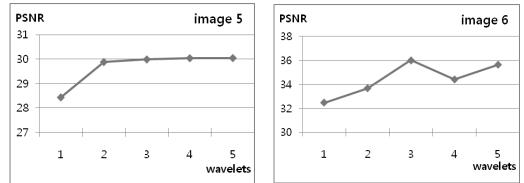


Figure 3. 2 patterns of PSNR variation for the daubechies family wavelets

Table 6. PSNR values for various wavelets in coiflet families

images	coif1	coif2	coif3	coif4	coif5
1	46.371	46.760	46.867	46.916	46.943
2	31.329	33.672	34.651	35.183	35.515
3	18.356	18.502	18.549	18.573	18.587
4	31.404	32.701	33.148	33.374	33.510
5	29.412	29.820	29.935	29.987	30.017
6	32.899	34.246	34.704	34.935	35.074
7	21.792	22.347	22.546	22.648	22.710
8	22.344	22.913	23.115	23.219	23.282

The length of db filter is getting longer as PSNR values is getting better, but the rate is getting smaller. There were three exceptions for images 3, 7 and 6. For the image 3 and 7, they show very similar pattern to pattern 1 except db11. The wavelet db11 has the higher PSNR value than that of longer filter db 14. Including the mage 3 and 7 for most of all images do not show the effectiveness after longer than the filter db8. The real small increasing PSNR value with longer filter make the calculation cost high. Hence it is not a bad idea to take db8 or db11 as the adequate filter in processing. For the case of image 6, db8 is the most suitable as shown in Fig. 3(b).

3.3 Result for coiflet wavelet family

Table 6 shows the PSNR values for each eight remotely sensed images with coiflet wavelets. There is only one pattern. The length of db filter is getting longer as PSNR values is getting better, but the rate is getting smaller. There was no exception for the coiflet family. They shows

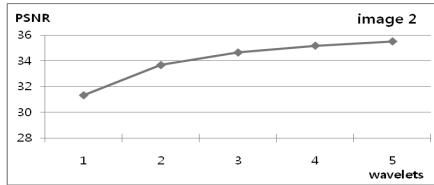


Figure 4. The pattern of PSNR variation for the coiflet family

the one type graph in Fig. 4. Coif3 or coif4 can be an effective filter in the sense of the calculation cost.

4. Experiment 3: Wavelet families for the image compression

The multiresolution analysis is very useful in the image compression. For two band filter it usually divide the image into four parts such as LL, LH, HL, and HH. Here H represents the high pass filtered image and L for the low pass filtered one. As mentioned in the experiment 1, the choice of wavelet can make the distribution of the energy in the four parts different. The multiresolution method analyzes the LL part again to make the level one up. Again the choice of wavelet is needed. At each level the PSNR values are calculated to find the maximum energy in the LL part as in the experiment 1. Hence, the many kinds of wavelet were used to horizontal and vertical direction separately. Three kinds of wavelet families in the experiment 2 were used. The level was tried up to three. Table 7 ~ Table 9 show the wavelet pairs which have maximum PSNR values at each level for sample images. In each table hf represents horizontal filter and vf does vertical filter. The numbering is followed the table 3.

For the biorthogonal families the wavelet pairs showing maximum PSNR values are different at each level in five images out of eight images. For the image 1, 5, 7 and 8 two kinds of wavelets were used to get the maximum PSNR values. But for the image 3 four kinds of wavelet were used. Total elapsed time to calculate the maximum PSNR value for each image was high. Hence finding the maximum PSNR values for image

Table 7. biorthogonal wavelet pairs with maximum PSNR values at each level

image	max PSNR						PSNR	
	Level 1		Level 2		Level 3			
	hf	vf	hf	vf	hf	vf		
1	5	1	5	5	5	5	46.884	
2	4	4	4	4	4	4	35.077	
3	3	1	2	5	2	5	18.571	
4	5	5	5	5	5	5	33.265	
5	1	1	5	5	5	5	29.963	
6	4	4	4	4	4	4	34.966	
7	1	1	5	5	5	5	22.599	
8	1	1	5	5	5	5	23.163	

Table 8. daubechies wavelet pairs with maximum PSNR values at each level

image	max PSNR						PSNR	
	Level 1		Level 2		Level 3			
	hf	vf	hf	vf	hf	vf		
1	4	5	4	5	4	5	46.956	
2	5	5	5	5	5	5	35.767	
3	4	4	4	4	4	4	18.610	
4	5	5	5	5	5	5	33.610	
5	5	4	5	4	5	4	30.040	
6	3	3	3	3	3	3	36.019	
7	4	4	4	4	4	4	22.756	
8	5	5	5	5	5	5	23.306	

compressions may cost too much.

For the daubechies families the wavelet pairs showing maximum PSNR values are identical at each level. It means that the nearly wavelet pairs can be predicted at the level one.

For the coiflet families the wavelet pairs showing maximum PSNR values are identical at each level. Even those wavelets are identical. It was the coif5 with longest filter length in the family. It means that the optimal wavelet pairs can be predicted at the level one.

Table 9. coiflet wavelet pairs with maximum PSNR values at each level

image	max						PSNR	
	Level 1		Level 2		Level 3			
	hf	vf	hf	vf	hf	vf		
1	5	5	5	5	5	5	46.927	
2	5	5	5	5	5	5	35.405	
3	5	5	5	5	5	5	18.578	
4	5	5	5	5	5	5	33.467	
5	5	5	5	5	5	5	30.009	
6	5	5	5	5	5	5	35.044	
7	5	5	5	5	5	5	22.686	
8	5	5	5	5	5	5	23.252	

5. Conclusions

Various kinds of wavelet pairs were examined to find the nearly optimal PSNR values in the remotely sensed image data compression. The nearly optimal wavelet pairs could be predicted in the level one for the orthogonal wavelet families. These results will be used for the compression of air photo mosaic, image encryption, image fusion, noise removal, and so on (Chun et al., 2005; 윤공현, 2006). There are four conclusions from three experiments.

- (1) The algorithm which pick the wavelet pairs using db1 wavelet works good for eight remotely sensed images.
- (2) For biorthogonal wavelet families the variation of maximum PSNR values was not predictable. The filter length of analysis and synthesis affects differently so that bior2.6 and bior6.2 are totally different. Therefore heuristic information about wavelet filter works more efficiently.

For daubechies wavelet families, the longer filter length showed higher PSNR values in many cases. But the increasing rate of PSNR values are getting less as

the filter length is getting longer. Even after db8 we could see degrading PSNR values in image 6. Therefore picking the wavelet with moderate filter length such as db8 may be more effective.

For coiflet wavelet families the variation of maximum PSNR values could be predictable. The longer filter length showed higher PSNR values. However the increasing rate of PSNR values is getting less as in daubechies wavelets. Therefore picking the wavelet with medium filter length such as coif4 or coif5 may be enough and efficient.

- (3) For biorthogonal families the wavelet pairs showing the maximum PSNR values are different at each level in five out of eight images. It means that it is hard to predict the optimal wavelet pairs from level 1.

For orthogonal families such as daubechies and coiflet wavelet the pattern of wavelet pairs giving the maximum PSNR values is consistent from level 1 to level 3. Therefore the optimal wavelet pairs can be predicted from level 1 for daubechies and coiflet wavelet families. The level one processing can be done as in experiment 1.

- (4) For all cases the compression rate can be detected roughly at level 1.

If the PSNR value in level 1 for some wavelet pairs is around 18, then for any other wavelet pairs the value is 10% more or less

Acknowledgement

This research was supported by the Korea Aerospace Research Institute through a grant from the KOMPSAT-3 system development project.

References

- 윤공현, 2006, SFR기법을 이용한 영상 융합의 정확도 향상에 관한 연구, 한국GIS학회지, 14(1), pp.85-94.
Anscombe, F. J., 1973, Graphs in statistical analysis, Am-

- erican Statistician, Vol.27, pp.17-21.
- Chae, G. J., Park, J. H., Park, J. H., and Kim, K. O., 2003, Compression of Landsat Image using the spectral property and wavelet filter, Proceedings on IGARSS 2003, Vol.6, pp.3583-3585.
- Chun, W. J., Joo, Y. J., Moon, K. K., Lee, Y. I., and Park, S. H., 2005, A GIS Vector Data Compression Method Considering Dynamic Updates, The Journal of GIS Association of Korea, 13(4), pp.355-364.
- Daubechies, I., 1992, Ten lectures on wavelets, SIAM, Philadelphia.
- Gladston, R. S., Revathy, K., and Raju, G., 2008, Study on the choice of wavelet filters for image compression using neural and k-nearest neighbor classifiers, Journal of Wavelet Theory and Applications, Vol.2, No.1, pp.15-30.
- Jin, H. S., Yoo, H. Y., Eom, J. Y., Choi, I. S., and Han, D. Y., 2009, Wavelet Pair Noise Removal for Increasing the Classification Accuracy of a Remotely Sensed Image, Korean Journal of Remote Sensing, Vol.25, No.3, pp.1-9.
- Mallat, S. G., 1998, A wavelet tour of signal processing, Academic press.
- Raghhuveer M. R., Ajit S. B., 1998, Wavelet Transforms, Addison Wesley.
- Strang, G., Nguyen, T., 1996, Wavelets and Filter Banks, Wellesley and Cambridge Press.
- Thomos, N., Boulgouris, N. V., and Strintzis, M. G., 2006, Optimized Transmission of JPEG2000 Streams Over Wireless Channels, IEEE Transactions on Image Processing, Vol.15, No.1, pp.54-67.
- Yoo, H. Y., Lee, K. W., Jin, H. S., and Kwon, B. D., 2008, Selecting Optimal Basis Function with Energy Parameter in Image Classification Based on Wavelet Coefficients, Korean Journal of Remote Sensing, Vol.24, No.5, pp.437-444.

Received	(November	9 2009)
Revised	(December	21 2009)
Accepted	(December	22, 2009)