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The Improved Embedded Zerotree Wavelet Coding (EZW) Algorithm

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Abstract. According to the high and low frequency distribution characteristics of wavelet coefficients that were given by Wavelet transform decomposition of images, in this paper, a improved algorithm was proposed for the disadvantage of the classic EZW. The improved algorithm included four steps to improve the coding efficiency of EZW: to predict low-frequency sub-band coding and code after move the forecasted errors by arithmetic coding; set a new threshold value for high-frequency sub-band to improve the quality of quantify; according to the characteristics of the human eye, improve the Diagonal direction threshold to increase the number of zero-tree; according to the table characteristics of the main scan, compressed image by improved huffman coding. Experiments show an improved effectiveness of the algorithm.

Keywords: image Compression; zero-tree coding; predictive coding; wavelet

1. Introduction

In recent several decades, wavelet image coding technology in the field of image compression has achieved a great success. Because of the multi-resolution characteristics of wavelet transform is very suitable for image compression, which can facilitate the construction of an embedded bit stream to achieve an embedded coding. Embedded encoder can be terminated at any point in the encoders and decoders can be truncated at any point in the bit stream, with the increase in received bits, it can be a gradual restoration of the image. Embedded codes are widely used in networking, wireless transmission, image browsing and other fields.

In the wavelet image coding, Embedded Zero-tree Wavelet coding algorithm (EZW) is one of the most classic and the first to be proposed wavelet encoder, it was proposed in 1993 by Shapiro. Its basic idea is to use the different scale correlation of wavelet coefficients. It put the majority of the zero coefficient of the organization into a tree structure. This algorithm received bit stream of bits is the order of importance, and can easily achieve the classification coding and transmission. Using this coding method, we can end the algorithm at any point, it allowed to reach a target bit rate or target distortion, but then it can still restore the original image accurately. EZW algorithm has milestone significance in the history of wavelet image coding.

Although the EZW algorithm is now acknowledged as more effective for wavelet image coding method, with deep study, we found that it is still inadequate [1]. for example, EZW algorithm code all the frequency domain of wavelet coefficients as the same importance, so the multi-resolution characteristics of wavelet transform is not sufficient to be used, the characteristics of wavelet transform image compression were not fully revealed; In EZW algorithm big factor is important than the small factor, it deals with the larger coefficients firstly, regardless of the location factor. In fact, according to human visual characteristics, a smaller coefficient of horizontal and vertical sub-graph sometimes is more important than a bigger coefficient of diagonal direction. This limited the compression ratio to improve.

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This paper based on the EZW algorithm, in accordance with its shortcomings, put forward several measures to improve the coding efficiency of the EZW.

2. Embedded Zero-Tree Wavelet Coding Algorithm [2-3]

EZW based on the characteristic distribution of wavelet transform coefficients, it is organized into the image shown in Figure 1 of the tree-wavelet zero-tree structure, and the tree structure is established by using the wavelet coefficients of similarity in the same direction. In figure 1, *LL* is a low-frequency, low-scale approximation of the filtered information; in the same level, *HL* contains the horizontal high-pass, vertical low-pass filtered details; *LH* contains the horizontal direction with a low-pass, vertical high-pass filtered details; *HH* contains the horizontal and vertical directions through the high-pass filtered details.

For the threshold *T*, if the wavelet coefficients *X* to satisfy $|x|\geq T$, then *X* for *T* is an important factor; if the wavelet coefficients *X* to satisfy $|x|<T$, then *X* for *T* is not an important factor; If *X* is not important factor, and all of its descendants are unimportant, we say that *X* is a zero on the *T* roots. If the coefficient *X* is not important, but it is important to children and grandchildren there, we say that *X* is an isolated zero on *T*.

EZW algorithm, the wavelet coefficients encode after repeated scans, each scan process as follows:

- Select threshold. For the L-level scanning, select threshold $T_i = T_0 / 2^L$, Initial $T_0 = 2^{\lfloor \log_2 Max\{|c_{i,j}|\} \rfloor}$,
- $c_{i,j}$ is the wavelet coefficients.
- Main scan. Wavelet coefficients compare with the threshold T_i, according to results of the comparison output of the following symbols: Positive important element *P*; Negative important element *N*; Zero roots *T*, Isolation zero *Z*. During the scanning process, Scanning table with a master record of the output symbols. The first i time after the end of the main scan, the output symbols for the coefficients of *P* or *N* to mark the corresponding position, in the next scan no longer code on them. Scanning sequence shown in Figure 2.
- Vice Scan. Scanning the table of the main sequential scan, one output of the symbol *P* or *N* of the wavelet coefficients to quantify.
- Reordering. The output symbol *P* or *N* to re-sort the data.
- Output of coded information.
- Repeat the above steps until you meet the required bit-rate encoding stops.

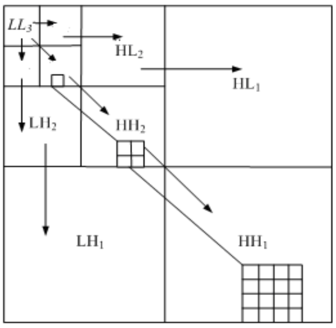

Fig. 1. Wavelet tree

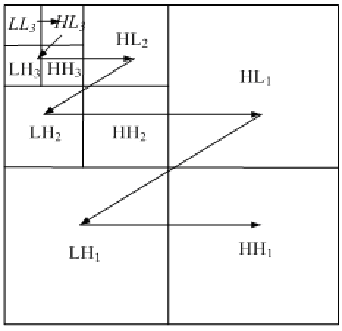

Fig. 2. Scanning order of wavelet coefficients

3. The Improved EZW

Improved scheme proposed in this paper mainly include the following four aspects:

3.1. Low-Frequency Sub-Band Coding

As we know, The original image after the wavelet transform, the energy concentrated in the low-frequency sub-band, it retains the large amounts of information of the original image, The correlation between wavelet coefficients is very high, Low-frequency sub-band between the adjacent pixels with a greater than the high-frequency sub-correlation, low-frequency sub-band coefficients are generally higher than those in high-frequency. The traditional EZW algorithm treat the most low-frequency sub-band as other high-frequency sub-band in compression, a smaller loss of low-frequency sub-band reconstructed image quality will be addressed to bring about a greater influence. Therefore, this paper uses a lossless compression to take low-frequency sub-band coding separate, it can ensure the quality of reconstructed image in this way. Taking correlation of wavelet in the horizontal and vertical directions into account. Therefore, it would be more effective use of predictive coding. Predictive coding program is pulse code modulation (DPCM) algorithm in this paper.

Therefore, the design of this paper is to solve the difference between each pixel in low-frequency sub-band *LL* $e(n) = f(n) - \hat{f}(n)$, $f(n)$ is the original signal, $\hat{f}(n)$ is the predictive value. Prediction error $e(n)$ is smaller than the original signal variance $f(n)$, so passing the $e(n)$ is better than the Original signal $f(n)$ for compression. The greater the relevance of $f(n)$ is, the smaller the variance of $e(n)$ is, and thus the smaller the source of uncertainty, the entropy source get smaller, It can achieve higher lossless compression ratio. Therefore, passing the $e(n)$ can get smaller rate than passing $f(n)$, this is precisely the prediction of the fundamental basis for image compression coding.

This paper use two-dimensional DPCM prediction method, for example, use a, b, c to forecast $f(n)$, get the current pixel $f(n)$ forecast $\hat{f}(n) = 0.5a + 0.25b + 0.25c$. It obtained prediction error coefficient, then mobile the error coefficient, to ensure that all prediction error coefficients are a positive number, to avoid coded symbols, and then encoded offset coefficient by arithmetic coding.

3.2. Dealing with High-Frequency Sub-Band Initial Threshold Value

As the low-frequency sub-band to save the image a lot of energy, therefore, the maximum of the wavelet coefficients is often found in the most low-frequency sub-band. EZW is to find the maximum ($Max\{|c_{i,j}|\}$) among the wavelet coefficients, on the basis of $T_0 = 2^{\lfloor \log_2 Max\{|c_{i,j}|\} \rfloor}$ to get the initial threshold value.

In this paper, it will carry out low-frequency sub-band alone by DPCM lossless encoding, low-frequency coefficient value is not recorded, therefore, this paper took the maximum high-frequency coefficient as the initial threshold value, it makes the threshold value decreases each scan, and improve quality and to quantify, it can reduce the scanning frequency, shorten the compression time. The initial threshold value of the original EZW algorithm can make error increasing, and is bad for the quality of image restoration.

3.3. The Threshold based on Visual Redundancy

People are those who judge the quality of image compression, according to human visual system characteristics, to remove the weak parts of human visual system can improve the compression speed and compression ratio. The human eye in different parts of the image the degree of sensitivity is different, the distortion of horizontal and vertical direction is less than the diagonal. according to this feature，this paper raises the threshold of the diagonal direction, remove unnecessary details to increase the zero-tree of diagonal direction. It is to some extent reduce the compression time and compression ratio. In this paper, the threshold of the diagonal direction is $1.3T_i$.

3.4. Improvement of the Main Scanning Table

In EZW wavelet coefficients compare with the levels of thresholds, and get a main scan table filled with four types of symbols. The *T* and *Z* are the main symbols in the main scan table, *P* and *N* are less than *T* and *Z*. This also illustrates the image by the wavelet transform has a good frequency-domain energy of aggregation.

Some literatures make processing on the main scan the table to achieve further compression. Such as the use of arithmetic coding and Huffman coding, Arithmetic coding has two processes: first, establish an information table, second scan and code the symbols; Huffman coding also statistics the frequency of each symbol, sorted by frequency of size and re-formation of binary tree and get all the symbol codes [4]. Therefore, arithmetic coding, Huffman coding will need to spend some computing time.

Because *T* and *Z* are the main symbols of the main scan table, the paper make improvement to the Huffman, The frequency of large symbols *T* and *Z* are expressed as brief binary code. Coefficients are given directly to the type code as shown in Table I:

Table 1 Coefficient of Type Code

Factor type	**Code**
Zero roots T	0
Isolation Zero Z	10
Positive factor P	111
Negative factor N	1100
End tag code	1101

This improved algorithm is more saving time than Huffman and Arithmetic Coding.

4. Simulation Analysis

In this paper, 256 × 256 × 8bit Lena image is example, simulation results, the program shown in Figure 3. First used CDF9 / 7 to make Image decomposition in 4, then respectively EZW algorithm and this improved EZW algorithm Lena image compression, The simulation results in Table 2, Figure 4below.

As can be seen from Table II, in the same bit rate, the MSE of Improved EZW algorithm is lower than EZW, The PSNR of Improved EZW algorithm is higher than EZW, these two indicators of the changes are showing the effectiveness of this improved algorithm.

As can be seen from Figure 4, the improved algorithm is better than EZW in Visual. This due to improved algorithms for the most low-frequency sub-band separately lossless coding, it makes the low-frequency sub-band of wavelet coefficients to be retained; set the high-frequency sub-band threshold, so that the threshold value is more reasonable and more accurate quantification; diagonal direction of the high-frequency sub-band threshold to take a quantitative approach, increasing the number of zero-tree; Huffman coding using an improved scanning table of the main compression. These measures effectively improved the peak signal to noise ratio and the encoding and decoding time.

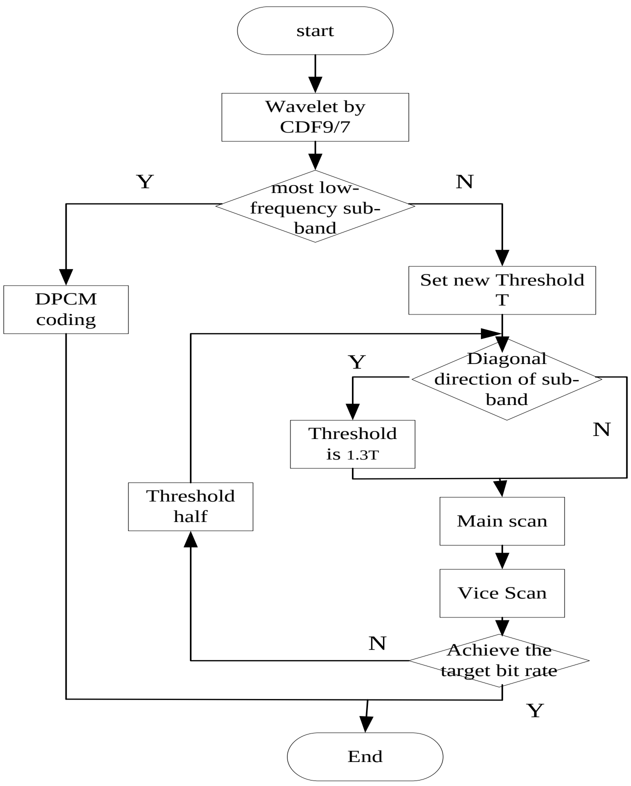

Fig. 3. Improved coding flowchart

Table 2 EZW algorithm and improved algorithm performance comparison

	MSE		PSNR（db）		Encoding and decoding time(s	
Rate	***EZW***	***Improved EZW***	***EZW***	***Improved EZW***	***EZW***	***Improved EZW***
1.0	52.7	20.9	34.8	36.5	35.9	26.7
0.5	121.8	49.7	30.1	31.6	18.6	13.8
0.25	239.2	99.6	27.2	28.1	10.1	8.3

(a) (b) (c)

(a)Lena (b) EZW Algorithm for Image Reconstruction
(c) Improved Algorithm for Image Reconstruction

Fig. 4. Improved Algorithm and EZW for Image Reconstruction

5. Conclusion

Based on the defect of embedded wavelet zero-tree algorithm, according to the characteristics of wavelet transform coefficients distribution, Improvement measures are given in detail, specific measures are divided into four-point: first low-frequency sub-band is coded, this will enable more of the important wavelet coefficients to be retained; second the remaining high-frequency sub-band to re-set the threshold value to improve the quality of quantitative; third improve the threshold based on human visual system to increase in the zero roots; fourth Huffman coding with improved compression of the main scan table. The simulation results show that the improved algorithm is better than EZW in terms of subjective visual and objective data.

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