An Image Compression Algorithm based on Wavelet Transform and LZW

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Abstract

In image compression, the compression rate of the traditional wavelet transform is low, and the time of both compression and decompression is too long while traditional compression coding method is used. In order to solve problems above, a compression algorithm for image combine wavelet transform with LZW was proposed. In this algorithm, a low frequency component and three high-frequency components of a image are obtained by using wavelet transform method. Then the low-frequency component that has been quantified with different degrees was converted to a one-dimensional vector as well as every high-frequency component, and the coefficients will be differentiated three times to be compressed with LZW compression algorithm. The results of test prove that the algorithm proposed in this paper can combine the advantages of both wavelet transform and LZW and optimize it. The method will facilitate the image transmission and image storage.

Keywords

Wavelet Transform, Image Compression, LZW Compression Algorithm, Quantization, Encoding.

1. Introduction

With the rapid development of computer technology, electronic information technology and communication technology, the image information can be used everywhere. However, the large amount of information contained in the image information brings great difficulties to the storage, processing and transmission. Therefore, image compression is very important and necessary [1]. To explore more efficient and better compression performance of image compression coding technology for image data storage and transmission is of great significance.

Discrete wavelet transform has been widely used in the field of image processing [2], such as font recognition, image denoising, etc.. Wavelet transform of the image signal is decomposed into low and high frequency component, and pixel value in low frequency component is approximate value, the other three sub signal display vertical, horizontal and diagonal [3] image details. LZW is a dictionary-based compression algorithm that does not need to statistic the source when it is used. It can generate the encoding dictionary and the decoding dictionary adaptively, and it is especially suitable for encoding the repetition character or character string [4]. In [5], a Huffman-based vector quantization image compression algorithm is used to effectively improve the data compression ratio. However, since the same status codebook is generated in the same size as the main codebook and Blocks must generate different status codebooks, the process will require very long time to encode. An improved LZW algorithm is used in [6] and a parallel wavelet tree coding method based on CUDA is proposed and in [7], which achieves the lossless compression of images. But in many applications, a certain degree of lossy compression of the image is allowed.

In this paper, according to the characteristics of wavelet decomposition image, the high-frequency signals are quantized in different degrees, and the difference between adjacent pixel values is obtained three times. A large number of zero coefficients are obtained for compression with LZW algorithm. The method can improve the compression efficiency, as well as shorten the compression time. The method proposed in this paper can improve the image transmission rate and reduce the storage memory.

2. Algorithm principle

2.1 Discrete Wavelet Transform

If we set an image signal whose size is $Nx \times Ny$ to be $f(x,y)$, the two-dimensional discrete wavelet transform formula of the signal is as follows:

$$W_{\varphi}(j_0,m,n)=\frac{1}{\sqrt{NxNy}}\sum_{x=0}^{Nx-1}\sum_{y=0}^{Ny-1} f(x,y)\varphi_{j_0,m,n}(x,y) \quad (1)$$

$$W^{i}_{\psi}(j,m,n)=\frac{1}{\sqrt{NxNy}}\sum_{x=0}^{Nx-1}\sum_{y=0}^{Ny-1} f(x,y)\psi^{i}_{j,m,n}(x,y)$$

$$i=\{H,V,D\} \quad (2)$$

Where j_0 is an arbitrary starting scale, $W_{\varphi}(j_0,m,n)$ coefficients define an approximation at scale, and $W_{\varphi}^{i}(j,m,n)$ coefficients add details of horizontal (H), vertical (V) and diagonal (D) directions to $j \geq j_0$. J = 1, 2, ..., J-1 and m, n = 0, 1, 2, ..., 2^{j}-1 are always selected. $\varphi_{j_0,m,n}(x,y), \psi^{i}_{j,m,n}(x,y)$ is corresponding wavelet function.

Two dimensional discrete wavelet transform is shown below:

$$f(x,y)=\frac{1}{\sqrt{NxNy}}\sum_{m}\sum_{n}W_{\varphi}(j_0,m,n)\varphi_{j_0,m,n}(x,y) + \frac{1}{\sqrt{NxNy}}\sum_{i=H,V,D}\sum_{j=j_0}^{\infty}\sum_{m}\sum_{n}W^{i}_{\varphi}(j,m,n)\varphi^{i}_{j,m,n}(x,y) \quad (3)$$

2.2 Selection of wavelet bases.

How to choose a suitable wavelet base is an important and difficult problem in the application of wavelet [8]. Comparison of the characteristics of commonly used wavelet basis is shown in Table 1 [9]. These features are related to how to select the appropriate wavelet base.

Table 1 Wavelet base and its characteristics

Wavelet basis	Vanishing moment	Orthogonality	Tight support	Symmetry
haar	1	Orthogonal	1	Symmetry
db	N	Orthogonal	2N-1	Approximate symmetry
bior	Nr-1	Orthogonal	2Nr+1	Asymmetry
coif	2N	Orthogonal	6N-1	Approximate symmetry
sym	N	Orthogonal	2N-1	Approximate symmetry
haar	1	Orthogonal	1	Symmetry

Haar wavelet structure is simple [2], and can be fast decomposition and reconstruction. In the compression of image data, the image is decomposed and reconstructed directly by haar (or db1, bior1.1) wavelet. The obtained image is almost completely invariable but other wavelet bases will bring some error. In order to facilitate the observation of the effect of this algorithm, this paper chooses haar wavelet basis as the wavelet base of image data compression.

2.3 LZW compression and decompression algorithm

LZW (Lempel Ziv Welch) is the earliest widely used general data compression method on computers [10]. LZW is a dictionary encoding, is to use the repeatability in the date to achieve compression. The specific implementation steps of LZW coding algorithm are as follows [11]:

(1) Initializing the dictionary, clearing the prefix P;

(2)Reading the next character as the current character C, and then format entry <P, C>;

(3) To determine whether the entry <P, C> is in the dictionary;

① If the entry is in, then we assign the number of the entry <P, C> to P;

② If entry is not in, we need add the entry <P, C> into the dictionary, and let P = C, then output P;

(4)To determine whether the string table is full or has been completed coding;

① If the code is full or complete, we clear the dictionary, loop steps (1) to (4).

② Otherwise, we set the end code.

(2) If not, we output the encoded data stream Related to P.

End of encoding.

LZW decoding is the inverse of LZW coding. When we execute the LZW decoding, we need loop read the code, and output the string corresponding to the code in the string table, and add a new item to the table.

LZW algorithm has the advantage of simple logic and fast achieving. The disadvantage is that generation and search of dictionary is based on sequential insert and retrieval mode, if we need to deal with a large amount of data, the algorithm will reduce the efficiency of the search.

3. Algorithm Flow in the paper

This paper presents a wavelet transform and LZW algorithm combined image compression algorithm flow shown in Figure 1.

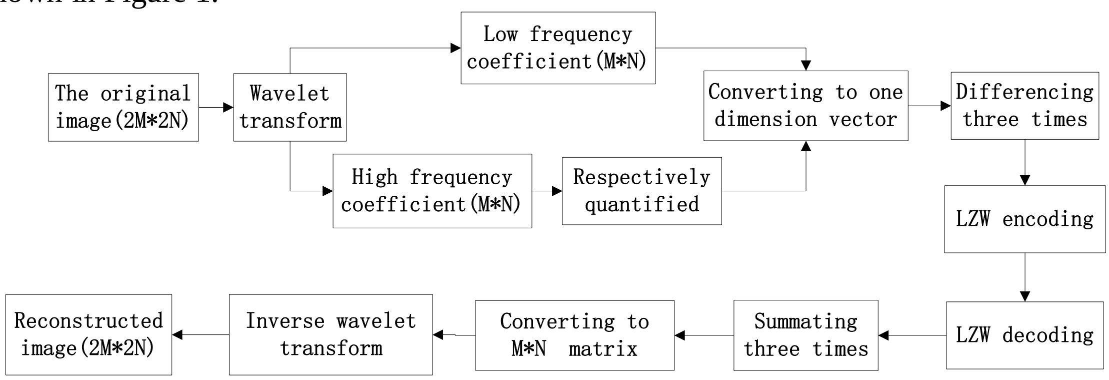

Figure 1: Algorithm Flowchart

Specific steps are as follows:

(1) The image is decomposed by wavelet to get the low frequency coefficients and the 3 high frequency coefficients of horizontal, vertical and diagonal directions.

(2)The high-frequency coefficients were quantified. The image information is transformed and encoded to obtain a series of transform coefficients. These coefficients have a large coverage area. To reduce the number of bits indicating the coefficient, the values within a certain range are classified and represented by the same data. The process is called quantification. In this paper, the process of reducing the size of the pixel value in the image to an integer near $1/n$ of the original value is referred to simply as $1/n$ quantization. The quantization process will inevitably produce a large amount of same data. In this paper, we use the method of 1/2 quantization to quantize the horizontal and vertical components and 1/4 quantization to quantize the diagonal component for the feature of wavelet transform decomposition image

(3) The low-frequency coefficient matrix and the quantized high-frequency coefficient matrix are subjected to the following processing: First, converting the matrix to a one-dimensional vector, and then obtaining the difference between the adjacent two numbers of the one-dimensional vector (the next number is subtracted from the previous number) to form a new one-dimensional vector. And then repeat this step on the new one-dimensional vector … after 3 times we get a one-dimensional

vector, the vector contains a large number of 0 value. The value of the vector will be compressed by LZW encoding to get bit stream. The first number of each new vector is retained to use in subsequent inverse operations. Because the time we use normal LZW algorithm to compress a image is too long, the LZW compression algorithm used in this paper is the algorithm that the data is difference processed three times the then using normal LZW algorithm to compress it. The LZW decompression algorithm contains three summation processes.

(4) Decompression process is the inverse process of (3). The coefficients obtained by decompression will be used to rebuild the image.

4. Result and Discussion

4.1 Evaluation Criteria for Compression

4.1.1 Subjective evaluation criteria

Subjective evaluation is a kind of test to determine the system performance directly using the subjective response of the viewer to the system image of the test system [12]. Subjective evaluation criteria are shown in Table 2 [13].

Table 2 Subjective evaluation criteria

score	Evaluation level	Evaluation scale
5	excellent	Very high quality image
4	good	High quality images that do not affect the viewing
3	medium	Image distortion less, slightly affect the viewing
2	poor	Image distortion, affect the viewing
1	bad	Image distortion too much, seriously affecting the viewing

4.1.2 Objective evaluation criteria

This paper takes five indicators (T1, T2, compression rate, PSNR and MSE) to measure the compression effect. In the experiment, the time T1 indicates the time between the original image and the LZW coding is completed. (If there is only the wavelet transform, T1 represents the time of using wavelet transform to decompose the original image. Other things later in the text like this). The time T2 represents the time from the beginning of LZW decoding to the image reconstruction is completed (Situation is like above). The compression ratio, MSE (Mean Square Error), PSNR (Peak Signal to Noise Ratio) are defined as follows:

(1)Compression ratio (*Rt, Rm*)

Compression ratio of reconstructed image:

$$Rt=\frac{s_1}{s_2} \tag{4}$$

Compression ratio of coding:

$$Rm=\frac{l_1}{l_2} \tag{5}$$

Where s_1 represents the number of reconstructed image bits and s_2 represents the original image bit number. And l_1 represents the length after LZW compression, l_2 represents the coding length before compression

The smaller the *Rt*, the greater the degree of image compression. If *Rt*=1, the image is lossless compression. The smaller the *Rm*, the greater the degree of encoding and compression, and the compression effect is better.

(2)Mean Square Error (MSE)

If a gray image contains $Nx \times Ny$ pixel, then

$$MSE=\frac{1}{NxNy}\sum_{i=0}^{Nx}\sum_{j=0}^{Ny}[f(i, j)-\hat{f}(i, j)]^2 \quad (6)$$

Where (i, j) is the coordinate value of each pixel of the image, $i\in[0,Nx-1]$, $j\in[0,Ny-1]$, $f(i, j)$ is the value of each coordinate pixel of the original image, and $\hat{f}(i, j)$ is the coordinate pixel value of the reconstructed image. Obviously, the larger the MSE, the greater the image distortion.

(3) Peak Signal to Noise Ratio (PSNR)

$$PSNR=10\lg\left(\frac{255\times255}{MSE}\right) \quad (7)$$

The higher the peak signal to noise ratio is, the smaller the loss of the reconstructed image, that is, the better the quality of the reconstructed image.

4.2 Experimental results and analysis

With a size of 256*256 Lena in the experiment, the original image is shown in Figure 2, after wavelet decomposition of the image is shown in Figure 3.Can be found on behalf of low-frequency image decomposition in the image on the upper-left section of the image is the most close to the original. And the lower-right section which represent the diagonal component has the largest gap between the original. This quantitative method proposed in the paper is based on this feature.

Figure 2: Original image

Figure 3: Wavelet decomposition of a layer

Figure 4: Wavelet decomposition and Reconstruction

Figure 5: LZW compression and decompression

Figure 6: Wavelet +LZW

Figure 7: Wavelet + 1/2 quantization

Figure 8: Wavelet + quantification of this article

Figure 9: Wavelet + 1/2 quantization + LZW

Figure 10: Wavelet + quantification of this paper + LZW

Figure 4 is reconstructed by decomposed pixel value matrix which decomposed by wavelet in a layer from original image. (Corresponding to Method 1 of Table 3 and the following method omits the term "Table 3"). Figure 5 is decompressed from vector from the original image is compressed with the LZW algorithm in the paper (Method 2).We can obtain four coefficient matrices after decomposition of the image with wavelet, which will be compressed to a vector with the LZW algorithm. Then the vector will be decompressed and reconstruct to image shown in Figure 6 (method 3). After wavelet decomposition, the high frequency coefficients will be respectively 1/2 quantified to three new coefficient matrices which will be reconstructed to image in Figure 7 with low frequency coefficient together(Method 4). Compare to method 4, if only the diagonal partial coefficient is 1/4 quantified, finally we will obtain image in Figure 6. On the basis of method 4 and method 5, the quantized coefficients are compressed by the LZW algorithm to three vectors. The vectors will be decompressed and reconstructed to image in Figure 9 and Figure 10 with low frequency coefficient (Methods 6 and 7) .Compare with original image in Figure 2, images in Figure 4, Figure 5, Figure 6 are very high quality images. Based on subjective evaluation criteria, evaluation level of the images is excellent and can get 5 points. Compared with the original figure Image in Figure 7, Figure 8, Figure 9, Figure 10 is a bit fuzzy, but the evaluation level is good. The images are still high-quality images, and do not affect the viewing, can get 4 points.

In order to facilitate the objective evaluation, the above methods are tested to obtain the objective evaluation index data which we base on establish a table as shown in table 3.

As can be seen from Table 3, mean square error between decompressed map and the original image is 0 in method 1 and method 2, the image is not distortion. From the data obtained by methods 1, 4, and 5, even if the quantitative process is added, the total time of wavelet decomposition and reconstruction is less than 0.1 second, which is almost negligible. If only the use of LZW algorithm, the compression time will reach 547.6986 seconds, but the LZW algorithm has the advantage of data compression and lossless recovery. In method 3, compression and decompression time is greatly reduced by combining wavelet and LZW algorithm, but *Rm* is higher than that of LZW algorithm only, and the compression effect is worse. Because the image is decomposed with wavelet and then is compressed with the LZW algorithm respectively, the same data between the various parts of the image can no longer be compressed together. In order to solve the problem of over-time in method 2 and the problem that the compression rate of method 3 is increased compare to method 3, in this paper we adopts the method of adding quantization process to improve the method 3. In contrast to method 4 and method 5 (or method 6 and method 7), it can be seen that the quantization method used in this paper is more advantageous than the high-frequency quantization in all aspects. The compression ratio (*Rm*) of the method 6 and method 7 is lower than that of the method 2, and the required time (T1, T2) are shorter.

Method 7 is the method proposed in this paper for the above analysis results. From the experimental results, we know this method can compress the wavelet decomposition data of the image to 0.45 times of original image, and the compression time is shorter than LZW algorithm, only 0.26 times of the latter, the decompression time is also only 0.45 times of the latter. In all lossy compression methods, the mean square error (MSE) of method 7 is the smallest and the peak signal-to-noise ratio (PSNR) is the highest. And the effectiveness of the proposed algorithm in the paper is verified.

Table 3 Comparison of compression effects of several methods

Method	MSE	PSNR	Rt	Rm	T1	T2
1	0.00	315.90	1.00	—	0.01	0.03
2	0.00	∞	1.00	0.47	547.70	2.29
3	0.00	52.94	1.00	0.63	234.24	1.52
4	110.05	27.72	0.88	—	0.01	0.03
5	108.13	27.79	0.85	—	0.01	0.03
6	110.16	27.71	0.89	0.47	149.04	1.16
7	108.13	27.79	0.85	0.45	142.32	1.06

5. Conclusion

The image compression algorithm in this paper combine the wavelet transform and LZW has the advantages of small reconstruction error, short compression time, low compression ratio and so on, which can make up the deficiency of traditional image compression algorithm. In this paper, the image is decomposed by wavelet transform, the high frequency data is processed by different quantization, and then the quantization coefficient will be compressed with the LZW algorithm .This algorithm can effectively improve the compression efficiency compare to traditional image compression algorithm. The algorithm proposed in this paper can help to reduce the image memory and improve the image transmission speed.

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