EZW-Based Image Compression with Omission and Restoration of Wavelet Subbands

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Abstract. It is well known that multimedia applications provide the user with information through different methods (text, data, graphics, images, audio, video, etc.) which must be digitally represented, transmitted, stored and processed. Due to the fact that there is an increasing interest in developing high definition systems, multimedia applications are demanding, among others, higher bandwidth resources and more memory requirements in embedded devices. Therefore, it is essential to use compression techniques to reduce the time requirements of these new applications. This work aims to design an EZW-based image compression model, which makes use of the omission and restoration of wavelet subbands, providing high compression rates, good quality standards and low computation time requirements. The results obtained show that our method satisfies these assumptions and can be integrated in new multimedia devices.

Keywords: Image Compression, Wavelet Transform, EZW Algorithm.

1 Introduction

Over the last few years there has been a massive demand for multimedia applications in telecommunication systems and, nowadays, it is still required to develop even more sophisticated methods who take into account new user requirements. On the one hand, the standardization of digital photography and the enormous growth in the number of the Internet users, has led to a considerable increase in using the Internet for exchanging images, videos or music. Consequently, file compression has become essential to reduce file size while maintaining maximum quality for these multimedia applications.

In addition, in order to satisfy the needs of both telecommunications platforms (reducing file size to optimize the use of the available bandwidth) and users (obtaining as much quality as possible), new multimedia mobile phone applications, such as video conferencing or capturing and sending still images and videos, need high performance compression schemes.

Furthermore, the JPEG still image compression, which is based in the Discrete Cosine Transform (DCT), became a standard in 1992. In recent years, though, there has been a considerable interest in methods based on the wavelet transform; in fact, the new standard JPEG-2000 uses wavelet-based compression methods [1], [2]. One of the most popular wavelet-based compression methods is known as Embedded Zerotree Wavelet (EZW) algorithm [3], [4]. In recent years, there has been an intensive research on improving this method and related ones, such as the Set Partitioning In Hierarchical Trees coding (SPIHT) [5], the Embedded Block Coding with Optimized Truncation (EBCOT) algorithm [6], and many others [7]. Although wavelet-based compression schemes have both better compression rates and higher quality results than JPEG algorithm, there are still major difficulties in achieving a high performance encoding system, since it is not easy to find an efficient implementation of wavelet transform calculations, which require huge memory sizes and consume many computer resources.

As a consequence, in this work we show a new EZW-based method, which omits and, afterwards, restores different resolution subbands, as it is described later. This algorithm provides better results than basic EZW: (i) considering both subjective and objective global image quality; and (ii) considering the restrictions of computational cost and memory storage of multimedia devices. To complete our task, in Sec. 2 we discuss EZW algorithm and the main advantages and drawbacks that it possess. Then, in Sec. 3 the design of a robust improvement for the EZW compression scheme is shown and, afterwards, Sec. 4 considers some of the experiments completed to verify that our system behaves properly. Finally, some important remarks to our work, as well as some future research tasks, are summarized in Sec. 5.

2 Overview of Image Compression Algorithms

2.1 Fundamentals of Image Compression

A digital image often has a strong correlation between pixels and, therefore, these contain redundant information. What is essential for efficient image coding is to find a representation of the image free from correlation. Thus, research on image compression is focused on reducing the number of bits necessary to represent an image, eliminating spatial redundancy as much as possible.

Lossy methods are most often used for compressing multimedia files, since they can produce a much smaller compressed file than any known lossless method, while still meeting the requirements of the application. Compression occurs by means of a linear transform to remove pixel correlation, then quantizing the resulting transformed coefficients and encoding them with minimum entropy.

Due to the huge amount of data involved and image redundancy, JPEG uses a DCT-based lossy compression scheme. The DCT itself does not carry out any compression, but transforms input data so that redundancy can be easily detected and eliminated. However, wavelet-based compression schemes usually improve image quality for high compression rates. We shall discuss this issue in the following section.

2.2 Wavelet Transform-Based Algorithms

Wavelets have become very popular in last years for different signal processing algorithms. Wavelets are functions defined in finite intervals with an average value of zero [8]; hence, they divide data into different frequency components so that each component can be studied with a resolution matched to its scale.

Wavelet-based image compression uses subband coding, in which an image is split up in frequency bands by means of a filterbank. Thus, a subband coding is a coding technique where the entry signal is filtered and separated in frequency bands combining a high-pass filter and a low-pass filter, with an average value of zero. There is a wide variety of wavelet functions to perform this transform, such as the Daubechies family, the Haar transformn, and many others [9].

The decomposition of images using wavelets is applied in the horizontal and vertical directions. An image is divided into subbands by passing it through a low pass filter and a high pass filter, and both subbands are downsampled by 2. This leads to a 2D signal getting broken down into four subbands, known as LL, LH, HL, and HH. The same procedure can then be applied iteratively to the LL subband, and repeated for as many levels of decomposition as desired.

Once the method is developed, the point is how to compress the wavelet-transformed data from an image. One of the most popular methods to do this is the Embedded Zerotree Wavelet Algorithm (EZW). Let us describe it next.

The EZW Algorithm. In 1993 Shapiro introduced a new algorithm known as *Embedded Zerotree Wavelet* for the entropic coding of the transformed coefficients of an image using the 2D wavelet transform [3]. The EZW algorithm states that if a coefficient at a certain level of decomposition is less than a significant level or threshold T , then all the coefficients of the same orientation in the same spatial location at lower scales of decomposition are not significant compared with T .

For every pass, a threshold T is chosen, against which all the wavelet coefficients are measured. If a wavelet coefficient is larger than T it is encoded and removed from the image, if it is smaller it is left for the next pass. When all the wavelet coefficients have been visited, the threshold is lowered and the image is scanned again to add more detail to the already encoded image. This process is repeated until all the wavelet coefficients have been encoded completely or another criterion has been satisfied.

The main advantage of this encoder is that it lets the encoding process end at any stage and, for this reason, the required compression factor is easily reached by trunking the encoding tree. Likewise, the decoder may also end the decoding process at any stage and, thus, generate a first approximation of the image. EZW encoding does not really compress data, but reorders wavelet coefficients in such a way that they can be compressed very efficiently; as a result, it should be followed by a symbol encoder, such as an arithmetic encoder. This algorithm obtains excellent results and has been object of intensive research since it was developed.

2.3 Discussion

The JPEG compression scheme is simple and has a very good performance, but since the input image is divided into 8×8 blocks, correlation across the block boundaries is not eliminated. This results in noticeable “blocking artifacts”, particularly at low bit-rates, as shown in Fig. 1 (a) and (c).

On the contrary, the EZW algorithm provides much better quality results at low bit-rates, as shown in Fig. 1 (b) and (d), where a Daubechies 9/7 wavelet function is used. This is due to the fact that the generated wavelet coefficient tree encodes significant data much more efficiently than the DCT and, consequently, it results in high quality compressed images.

Fig. 1. EZW compression compared to JPEG: For 0.5 bpp: (a) JPEG; (b) EZW. For 0.25 bpp: (c) JPEG; (d) EZW

Nevertheless, it must be remarked that the time spent to efficiently compress/decompress image data with EZW are much higher than the ones used for standard JPEG. For instance, the compression/decompression time for a 256×256 image is about 27.5 times faster for JPEG than for EZW -using a Pentium M processor and a C++ environment- and, what is more, this fact becomes even worse when image size increases.

To sum up, we can establish the main drawbacks of both systems. Firstly, JPEG algorithm generates a significant loss of quality at low compression rates and, on the other hand, EZW method requires a very high processing time, which makes it difficult to be applied in a real-time condition. Therefore, these two constraints are the initial step to develop a new approach that overcome these problems. This issue is considered in the next section.

3 Omission and Restoration of Wavelet Subbands

As derived from the review of the main methods for image compression, our research has focused on two different aspects: reducing the computation time of wavelet-based methods while keeping as much quality as possible.

In order for the computation time to be decreased, our proposal is based on reducing the image size so that the number of operations for checking descendants in the EZW algorithm would be also reduced. Therefore, the method consists of:

1. Carrying out an iteration of the wavelet transform on the input image.
2. Considering only the LL subband, making the rest of subbands equal to 0.
3. Compressing the LL subband using the EZW algorithm.

This method significantly reduces the processing time for compressing/decompressing an image, as it will be shown in Sec. 4. However, the problem is that by eliminating the subbands, a pixel of the decompressed LL subband is now transformed into a group of four pixels (its descendants) in the restored image, which means quite a visible distortion.

Subsequently, the next step is to improve image quality. In order to minimize distortion when recovering images, the eliminated subbands can be restored, thus reducing the global error. The subband restoration process is carried out once the LL subband has been decompressed, using the EZW algorithm; hence, each 4×4 block B , whose pixels are descendants of another pixel a in the previous subband, will take the value V of their ancestor a . That is, V is the mean value of the descendants of a in the original eliminated subband. As a result, our system distributes the error uniformly so that it is unlikely to be perceptible by the human eye.

As a result, our compression method is called Omission and Restoration of Wavelet Subbands (ORWS), due to the fact that it removes high frequency subbands before the compression and, afterwards, it restores them to minimize distortion. Figs. 2 and 3 show how the ORWS algorithm works.

Fig. 2. The subband restoration process

In the next section we shall analyze some different tests carried out to validate our algorithm.

Fig. 3. Block diagram of the ORWS algorithm

4 Experiments

Let us show now the results of some experiments completed for our method. Thus, we will compare the ORWS algorithm with the EZW compression method, and also with standard JPEG compression scheme. The tests have been performed with a series of well-known images, and we found that the results obtained with the ORWS compression scheme confirm the reduction in compression time and the increase in image quality regarding JPEG and EZW algorithms. For illustrations, the results for 512×512 , 8-bit gray-level images “Barbara” and “Lena” are shown in Figs. 4 and 5, respectively, using the Daubechies 9/7 wavelet.

Fig. 6 (a) shows the mean gain in the execution time of the ORWS algorithm (compression/decompression) in relation to the EZW method, for all the images in the database. Finally, Fig. 6 (b) compares the performance of ORWS, EZW and JPEG methods by using the mean peak signal-to-noise ratio (PSNR, see [10] for a definition of this ratio) for all the images in the database.

Fig. 4. ORWS for *Barbara*: (a) Original; (b) 0.5 bpp; (c) 0.25 bpp; (d) 0.125 bpp

Fig. 5. ORWS for *Lena*: (a) Original; (b) 0.5 bpp; (c) 0.25 bpp; (d) 0.125 bpp

Fig. 6. (a) Time gain of ORWS in relation to EZW; (b) Comparison of PSNR between ORWS, EZW and JPEG

From these results, we must remark that ORWS can run even 30 times faster than EZW (Fig. 6 (a)) and that it leads to higher quality compressed images than EZW and JPEG (Fig. 6 (b)), as it has higher PSNR values. As a result, the ORWS algorithm is a powerful tool for increasing both the computation time of wavelet-based compression schemes and the image quality of EZW and standard JPEG. As a conclusion, our method is a robust technique for compressing images and, consequently, improves existing methods both visually (subjectively) and objectively.

5 Conclusions

With the increasing use of multimedia technologies, image compression requires higher performance as well as new features. From our research, it can be extracted that all the existing compression algorithms have limitations under certain conditions. In particular, JPEG generates low-quality images when high compression rates are needed. On the other hand, EZW method has a very high computation time, which makes it difficult to be included in real-time applications.

In this work, the ORWS algorithm, which is based on the EZW compression method, has been proposed. The experimentation shows that our technique is fast, robust and provides high quality results. To summarize, the main advantages of our algorithm are:

- It is easy to implement and computational costs are low, while keeping good quality standards.
- It improves the quality of DCT-based image compression schemes, such as JPEG, for high compression rates.
- It reduces the processing time of wavelet-based algorithms.

As a future work, we consider the extension of the algorithm to color image compression. It would be also interesting to include other mathematical tools, such as interpolation techniques, to increase the performance of the wavelet subbands restoration process.

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