A Novel Implementation of JPEG 2000 Lossless Coding Based on LZMA

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Abstract

Faced with drawbacks of JPEG 2000 lossless coding in network application as far as manipulation flexibility is concerned, this paper proposes a differential approach of implementation. By combining JPEG 2000 lossy coding with LZMA compression, we come to a novel pattern which is more flexible and convenient while maintaining high compression ratio comparable to JPEG 2000 lossless coding. We evaluate the performance of our implementation in line with experimental results regarding compression ratio and analyze the prospective fields this differential implementation may well apply. An outlook of future work is also included.

Keywords: JPEG 2000; LZMA; Lossless Coding; Lossy Coding; Image Compression; JPD

1. Introduction

JPEG, the first international standard of still image compression, achieved remarkable success almost immediately after being published by virtue of high compression ratio and excellent quality. None the less, with the unceasing development of image processing techniques and the growing popularity of Internet, JPEG could no longer meet the rising demands of numerous uprising applications in aspects such as image quality, display methods and even transmitting methods. In December 2000, a replacing standard which employs DWT (Discrete Wavelet Transform) – JPEG 2000 – was published, bringing with it a number of significant improvements in comparison with JPEG: Higher compression ratio, advanced progressive transmission, random access mechanism, manipulation capability in the decoding process and region of interest (ROI). Besides, JPEG 2000 provides lossless coding, which is hard to implement in JPEG. As far as network application is concerned, however, the lossless coding of JPEG 2000 is to some extent inconvenient for lack of flexibility. Although lossless decoding can be ultimately achieved by transmitting more bits in a progressive manner, it is only applicable when displaying the image. The user at the receiving end is unable to save the image as an intact JPEG 2000 file before transmission of the whole image is complete, unless an extra re-encoding operation is performed. Even if the user is patient enough to wait till the end of transmission, what he or she gets at last is a sizable file in a lossless coding format. When needs arise to deliver the image in a lossy format, as is frequently the case in a network application, the image has to be re-encoded, which results in extra cost on both time and computing resources.

This paper focuses on solving the problems mentioned above in a simple, flexible and efficient fashion without introducing complicated manipulation of any form, while maintaining the maximum of compatibility with the original JPEG 2000 architecture. In Section 2 and Section 3, the theoretical bases of JPEG 2000 lossless coding and LZMA compression are described, respectively. Section 4 chiefly deals with the details of our implementation of lossless coding, including its rationale and architecture. In section 5, experimental results are shown with a view to evaluating the performance of our implementation. Section 6 analyzes the scope of application of our implementation and finally in Section 7, the conclusion and a prospect of future work are given in a brief manner.

2. JPEG 2000 lossless coding

Reversible DWT is one of the vital theoretical bases of JPEG 2000 lossless coding. A brief description of its fundamentals [1] is given as follows:

An input sequence x[n] of finite length can be converted into two sub-band sequences – y_0[n] and y_1[n]. The former can be interpreted as a low-pass sub-band while the latter a high-pass sub-band. For the sake of convenience, the low-pass sub-band and the high-pass sub-band can, according to Equation (1) and Equation (2), be interleaved to form a single sequence y[n].

$$y[2n] = y_0[n] \quad (1)$$

$$y[2n+1] = y_1[n] \quad (2)$$

The sequence x[n] and the sequence y[n], which are both defined in the domain [E, F), are extended according to Equation (3), Equation (4) and Equation (5).

$$\breve{a}[n] = a[n], E \leq n < F \quad (3)$$

$$\breve{a}[E-n] = \breve{a}[E+n], \forall n \in Z \quad (4)$$

$$\breve{a}[F-1-n] = \breve{a}[F-1+n], \forall n \in Z \quad (5)$$

JPEG 2000 Part 1 [2] has defined only one reversible DWT, which is described by Equation (6), Equation (7), Equation (8) and Equation (9).

a. Analysis:

$$\breve{y}_1[n] = \breve{x}[2n+1] + \left\lfloor \frac{1}{2}\breve{x}[2n] + \frac{1}{2}\breve{x}[2n+2] \right\rfloor \quad (6)$$

$$\breve{y}_0[n] = \breve{x}[2n] + \left\lfloor \frac{1}{2} + \frac{1}{4}\breve{y}[2n-1] + \frac{1}{4}\breve{y}[2n+1] \right\rfloor \quad (7)$$

b. Synthesis:

$$\breve{x}[2n] = \breve{y}[2n] - \left\lfloor \frac{1}{2} + \frac{1}{4}\breve{y}[2n-1] + \frac{1}{4}\breve{y}[2n+1] \right\rfloor \quad (8)$$

$$\breve{x}[2n+1] = \breve{y}[2n+1] + \left\lfloor \frac{1}{2}\breve{x}[2n] + \frac{1}{2}\breve{x}[2n+2] \right\rfloor \quad (9)$$

3. LZMA compression

The probability characteristics of many signals in real life, such as images and voices, are always changing. Traditional compression techniques, which are essentially based on probability statistics, are hardly applicable to the data generated by such signals. LZ77 [3], which is a probability-independent compression algorithm, may well serve the purpose. LZ77 is a string-based algorithm employing a dictionary compression scheme. Its work flow can be described as follows: The encoder has a sliding window comprising two parts – a search buffer, which is in effect the left part, and a lookahead buffer, which is in effect the right part. During compression, the string in the window moves from the right to the left. The string in the search buffer is the one recently encoded, and serves as the dictionary. The string in the lookahead buffer, on the other hand, is the one to be encoded. In the compression process, the encoder searches in the search buffer the longest pattern that matches the pattern in the lookahead buffer. If a pattern is found (the pattern is greater than zero in length), it is encoded with a combination of offset, length and the next symbol in the lookahead buffer. Otherwise, the first symbol in the lookahead buffer is encoded unchanged.

LZMA (Lempel-Ziv-Markov chain-Algorithm) is an optimized version of LZ77. It raises the compression ratio dramatically while maintaining high decompression speed and low memory requirements for decompression.

4. A novel lossless coding implementation

4.1. A differential approach

In view of the drawbacks of JPEG 2000 lossless coding emerging from network application, we set forth a solution that combines JPEG 2000 lossy coding with LZMA compression. A complementary file type, JPD (JPEG 2000 Differential), which employs LZMA compression, is defined in this paper in addition to JPEG 2000 lossy format (JP2). The JP2 file in question can function as an average JPEG 2000 file in the absence of its corresponding JPD file, which implies that we don't need to alter the JP2 file format in any way, thus ensuring the maximum of compatibility. In that case, the only disadvantage is that the image quality is comparatively low. Nevertheless, when the JPD file is present, the image can be losslessly decoded, presenting the best quality. In a network context, the user can download lossy JP2 file, which is usually quite small and takes a very short period of time to be transferred. If needed, the JP2 file can also be progressively displayed during the download process. The user need not re-encode the image if delivery of a lossy format is required at a later point of time, for what he or she has downloaded is already an intact lossy image file. Provided that the user is still not satisfied with the quality of the lossy image, he or she can download or even batch-download the corresponding complementary files, thus obtaining a lossless format eventually. At this point, the image needn't be displayed during the download process and therefore the complementary file can be compressed using any JPEG-2000-independent algorithm, such as LZMA, as is the case in this paper.

4.2. Encoder and decoder procedures

4.2.1. Encoder. As is illustrated in Figure 1, the encoder mainly performs the following tasks: (1) Encode the source image into a lossy JP2 file, (2) decode the JP2 file encoded into a reconstructed image, and (3) compress, using LZMA compression, the difference between the source image and the reconstructed image into a JPD file. The input of the encoder can be an image file of any uncompressed format, such as BMP or PPM while the output consists of two files – a JP2 file and a JPD file.

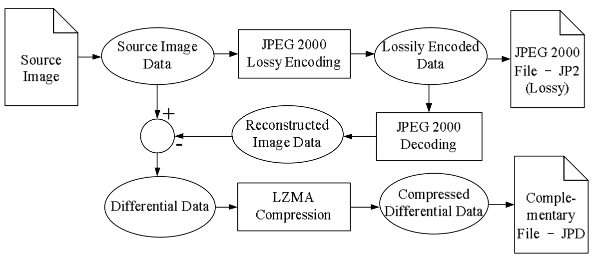

Figure 1. Encoder

4.2.2. Decoder. As is illustrated in Figure 2, the decoder mainly performs the following tasks: (1) Decode the JP2 file into a reconstructed image, (2) uncompress the JPD file to generate the differential data, and (3) restore the original image by adding the differential data to the reconstructed image data. The input of the decoder can be either a JP2 file along with its corresponding JPD file, or a solitary JP2 file. In the former case, the output is the restored image that is exactly the same as the source image in the encoder procedures.

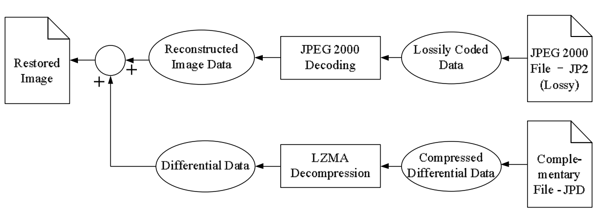

Figure 2. Decoder

4.3. JPD file format

7Z is the default output file format of 7-Zip archiver and it can be used to wrap up LZMA compressed data. The file format JPD defined in this paper is practically a re-wrapping of 7Z. The structure of a JPD file is illustrated in Figure 3.

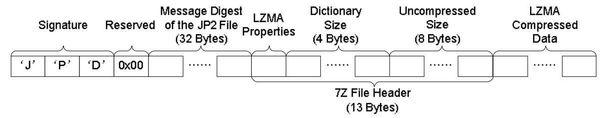

Figure 3. JPD file format

The association between a JP2 file and its corresponding JPD file should always be carefully maintained. Otherwise the image would be prone to integrity attacks, for a fake JPD file may try to alter the image content by pretending to be associated with a certain JP2 file. Therefore, having the JP2 file and its corresponding JPD assume the same file name simply wouldn't suffice. Taking into account this security issue, the JPD file format is designed to include a "digital signature" field which contains a message digest (MD5) of the associated JP2 file. Another advantage of including this field is that even if the file name is missing or corrupted, the association between a JP2 file and its corresponding JPD file won't break up.

In most cases, the difference between the source image and the reconstructed image in the encoder procedures is far from noticeable. Nevertheless, there are occasions when a difference value exceeds the bounds of range a signed byte corresponds to, namely, [-128, 127]. An escape symbol, '0x80', is defined in our implementation to cope with such situations. Each time an out-of-range difference value is detected in the encoder procedures, an escape symbol is inserted, with a two-byte signed representation of that difference value immediately following the escape symbol. With the employment of such a mechanism, the valid value range that a single-byte difference corresponds to is altered from [-128, 127] to [-127, 127], accordingly.

5. Experimental results

Experiments were made with three standard test images, namely, "Baboon", "Lena" and "Peppers", all in the format of 24-bit RGB. The bitrate for JPEG 2000 (Lossy) is 2.4 bits per pixel (bpp).

5.1. Compression of differential data

Differential data were respectively compressed using LZMA and JPEG 2000 (Lossless). And the compression ratios obtained are given in Table 1.

As is shown in Table 1, LZMA achieved better compression ratio than JPEG 2000 (Lossless), which suggests that LZMA enjoys superiority over JPEG 2000 (Lossless) as far as differential data compression is concerned.

Table 1. Compression ratio of differential data

Image	LZMA (Normal Compression)	JPEG 2000 (Lossless)
Baboon	67.97%	68.62%
Lena	48.70%	49.74%
Peppers	54.30%	55.21%

5.2. Overall compression ratio comparison

As is shown in Figure 4, although the JPEG 2000 lossless coding system generates only one file for each image compressed while our differential coding implementation generates two, the total size of the JP2 (Lossy) file and the JPD file is almost the same as the JP2 (Lossless) file. Put another way, our implementation has achieved a compression ratio comparable to JPEG 2000 lossless coding while offering far greater flexibility and a maximum of compatibility at the same time.

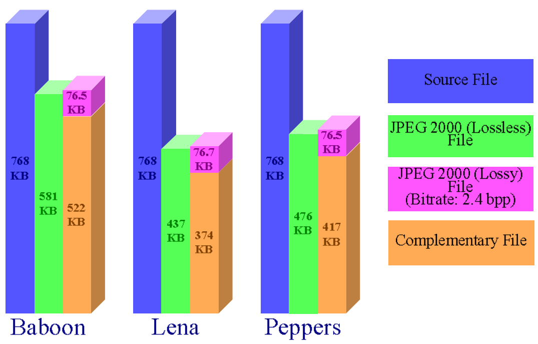

Figure 4. Overall compression ratio comparison

6. Scope of application

The differential coding implementation we propose in this paper may find valuable application in fields where remote retrievals of images of extra high quality occur on a very frequent basis, such as medical imaging, satellite imaging and artwork imaging. A database storing medical images may be a case in point. Suppose a doctor intends to make researches on cases of a certain disease. He needs to review medical images characterized by a very rare symptom, which requires him to browse through all the images concerned to sieve out the ones that matches the symptom. However, it usually takes quite some time to transfer a high-quality medical image which is losslessly encoded, let alone a good many of them. A feasible solution is to, in the first place, transfer the medical images encoded in a lossy format, which takes far less time. After the doctor has sieved out the images he needs locally, corresponding complementary files may be downloaded to obtain the best image quality, as is demanded by close scrutiny. Moreover, if problems arise that preclude appraisal and the doctor in question needs to discuss with other doctors about it, the lossy format of the image, which is quite small in size, may be transmitted, eliminating extra consumption on time for re-encoding.

Furthermore, such an implementation also contributes to an optimized resources utilization in an client-server context. On the one hand, smaller image files of JPEG 2000 lossy format may be stored on a cluster of servers that are fast but small in storage volume. Hence, retrieval requests sent to those servers can always be quickly responded. Larger complementary files, on the other hand, may situate on another cluster of servers that are slow but adequate in space of storage. Thus, download requests of complementary files, which occur at a far less frequency and require still less computing resources, can always be decently served.

7. Conclusion and future work

This paper has proposed a novel implementation of lossless coding, combining JPEG 2000 lossy coding with LZMA compression. Experimental results as to compression ratios have demonstrated that the proposed implementation possesses a fairly good compression capacity that is comparable to JPEG 2000 lossless coding. Hopefully, it may serve numerous purposes in network applications.

Future work chiefly consists in bettering compression ratio by optimizing LZMA, as well as enhancing error resilience capabilities by adding a certain kind of error-correcting code in the complementary file.

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