Reliable Adaptive Watermarking Scheme Integrated with JPEG2000

Kan Li and Xiao-Ping Zhang
Department of Electrical & Computer Engineering,
Ryerson University, 350 Victoria Street
Toronto, Ontario, CANADA, M5B 2K3
kli, xzhang@ee.ryerson.ca

Abstract

In this paper, a new digital watermarking method, integrated with the state-of-the-art image compression standard -- JPEG 2000, is developed. The binary digital watermark is embedded in the quantized wavelet coefficients in subbands with intermediate resolution after the stage of quantization and recovered before dequantization during decompression. Different from previously proposed JPEG 2000 based watermarking schemes, the compression ratio, regarded as an important parameter, is used to design the new adaptive watermark encoder. The strength of watermark is designed as proportional to the compression ratio such that the embedded watermark can survive the following code-stream rate allocation procedure without degrading the image quality. The experimental results show that the proposed system is robust to common image distortions and processing.

1. Introduction

With the high-capacity digital recording device, coupled with the recent growth of networked multimedia systems, the protection of ownership and prevention of unauthorized tampering of multimedia data become important concerns. Techniques to place an indelible message, known as digital watermark, into host data to demonstrate and protect the copyrights of digital products have achieved considerable progress in recent years. To protect copyright successfully, there are several fundamental requirements for watermarking. A watermark should not affect the commercial or art value of the host. A watermark should be resistant to a variety of manipulations, either unintentional or malicious. The detection should be accurate and especially the false-alarm rate should be very small. There might be other requirements, such as blind detection, for those applications where the access to the original host data is impossible.

It has been noticed that image compression and image watermarking share some common characteristics [1]. Significant frequency coefficients are encoded first both for image compression and for watermark embedding in image watermarking. Hence by integrating frequency domain watermarking with compression processes, the expensive image transform computation can be saved. On the other hand, combining image coding and image watermarking is highly desired in some classical applications, such as copyright protection, copy and access control and annotation, where image compression is performed before spreading abroad.

In this research, we investigate an algorithm integrating image watermarking into compression. The image compression scheme, on which our watermarking approach is based, is the latest still image compression standard, JPEG2000. The JPEG2000 image compression system has a rate-distortion advantage over the JPEG baseline system [2][3]. It provides subjective image quality performance superior to existing standards. Due to Embedded Block Coding with Optimized Truncation (EBCOT), it allows progressive transmission by quality, resolution, component, or spatial locality.

The block diagram of the JPEG2000 encoder is illustrated in Fig. 1. Discrete wavelet transform (DWT) is first applied to the source image data. The transform coefficients are then quantized and entropy coded, before forming the output code-stream. The decoder is the reverse of the encoder. The code-stream is first entropy decoded, de-quantized and inverse discrete transformed, thus resulting in the reconstructed image data.

Several attempts to introduce image watermarking technique into JPEG2000 system have been reported in the recent literatures [1, 5]. Both [1] and [5] embed watermark into the wavelet domain. In [1], a Gaussian noise sequence is generated as watermark and wavelet coefficients. The coefficients that are larger than a certain threshold value δ are selected to bear watermark. To detect the embedded watermark, reference watermarks are necessary in cross-correlation calculation. In [5], a blind watermarking technique is established by a spread-transform dither modulation algorithm. Non-overlapping windows are used over the entire code-block. At each window position, one bit of watermark message is embedded. For a code-block of the high frequency subbands, a larger embedding window is used because of the lower energy. Although both the algorithms fit into JPEG 2000 coding pipeline, some JPEG2000 features such as rate control are not explored.

In JPEG2000, to generate an optimal image for a target file size (bit-rate), a rate control process is performed after entropy coding. In [3], an efficient rate control method is proposed that achieves a desired rate based on *post-compression R-D optimization*. The rate control algorithm finds the optimal bit allocation for all code-blocks, such that the total distortion is minimized subject to the target bit-rate. Clearly the distortion brought by the rate control threatens the existence of watermark. The strength of watermark should be related to the compression ratio or bit-rate. For mild compression, the rate distortion is small and the energy of watermark should be low to maintain the image quality as good as possible. On the contrary, for higher compression ratio, the energy of watermark should be high enough to survive strong distortion caused by rate control. Furthermore, with declined image quality caused by compression, even a strong watermark becomes imperceptible. In our new watermarking algorithm, wavelet coefficients are modified depending on the compression ratio (bit-rate). A weak watermark is embedded into a mildly compressed image, while a strong watermark is applied to heavily compressed image.

It is shown in this paper that the new adaptive method integrates with JPEG 2000 standard very well. The watermark is detected in a simple and fast way without assistance from either the original image or the reference watermarks. Meanwhile, by taking into account the compression ratio, the tradeoff between imperceptibility and robustness is balanced. In section 2, the new watermarking approach is described in detail. Several experiment results are presented and discussed in section 3. The paper is concluded in section 4.

2. Watermarking Strategy

2.1 Watermark Embedding

In the proposed watermarking method, watermark is embedded into the sub-bands with intermediate resolution after stages of quantization and region of interests (ROI) scaling. During the stage of quantization, a wavelet coefficient $y_b(u,v)$ in subband b is mapped to a quantized index value $q_b(u,v)$. It is then normalized as the most significant bit (MSB) carrying the sign bit and the remaining bits represent the absolute magnitude of the coefficient. In this work, we assume that 8 bits are utilized to represent the integer part of $q_b(u,v)$. Thus the values of wavelet coefficients fall into [-255,255].

For wavelet coefficients, the operation of finding the optimal truncation point is nothing but performing an optimal non-uniform scalar quantization. Table 1 shows the value of some wavelet coefficients before and after rate allocation with different target bit-rate f. As can be seen, the degree of quantization highly depends on f. For watermark embedding, it is not necessary to estimate the accurate quantization step. We only estimate a coarse quantization interval Q as a parameter to determine the watermarking embedding level. We prefer Q a little bit larger than the true quantization interval, especially when the compression ratio is low, in order to reliably decode the watermark. The basic idea is to make the image distortion caused by the watermarking conforming to the image distortion caused by the rate-control distortion such that the watermark embedding capacity is maximized.

Table 1. Example wavelet coefficient values before and after rate control with different φ (coefficients are obtained from 3HH subband of image "Baboon" with Jasper [6]).

original value	f= 1	f= 0.625	f= 0.5	f= 0.25	f= 0.1	f= 0.08
2	2	3	0	0	0	0
12	12	14	12	0	0	0
23	23	22	20	24	0	0
-32	-32	-34	-36	-48	-48	0
45	45	46	44	48	48	0
-66	-66	-66	-68	-80	-96	-64
104	104	106	108	112	96	128

Table 2. Estimated quantization intervals for different bit-rate value.

bit-rate f	estimated interval Q
>1	2
1~0.8	4
0.8~0.5	8
0.5~0.25	16
0.25~0.2	32
0.2~0.1	48
<0.1	64

The watermark embedding system is shown in Fig. 2(a). The binary watermark w is embedded into selected code-blocks through the following steps:

Step 1. Estimate quantization interval Q with the provided target bit-rate according to the certain rate control scheme. Table 2 shows an example.

Step 2. Each watermark bit to be embedded is repeated M times for the purpose of error correction. M is also adaptively determined by f. The watermark bits embedded in images with less repetition are more fragile to the image distortion and processing and a larger M is necessary to improve its robustness.

Step 3. Coefficients belonging to [-Q/2, Q/2] are excluded to bear watermark. Since these small coefficients represent the flat area of an image, it is difficult to use them to bear watermark without significantly distorting the image.

Step 4. Positive coefficients are mapped to the nearest even multiples of Q, except 0, to embed bit "0" and the nearest odd multiples of Q to embed "1". Negative coefficients are mapped to the nearest even multiples of Q, except 0, to embed bit "1" and the nearest odd multiples of Q to embed bit "0". As shown in Fig. 2 (b), the filled and empty circles represent the intended points for bit "1" and bit "0" respectively. The above operation of encoding bit "1" and "0" can be formulated by the following equations:

$$y=\begin{cases}\left[\left(\left\lfloor \frac{x}{2Q}\right\rfloor+0.5\right)\times 2Q\right], & x>2Q\\ \left[\left(\left\lceil \frac{x-Q}{2Q}\right\rceil\right)\times 2Q\right], & x<-Q\\ Q, & Q/2\le x\le 2Q\\ -2Q, & -Q\le x\le -Q/2,\end{cases} \quad (2)$$

$$y=\begin{cases}\left[\left(\left\lceil \frac{x+Q}{2Q}\right\rceil\right)\times 2Q\right], & x>Q\\ \left[\left(\left\lfloor \frac{x}{2Q}\right\rfloor-0.5\right)\times 2Q\right], & x<-2Q\\ 2Q, & Q/2\le x\le Q\\ -Q, & -2Q\le x\le -Q/2.\end{cases} \quad (3)$$

2.2 Watermark Retrieval

The watermark is decoded before dequantization during image decompression. In terms of the bit-rate of compressed image, we can infer the quantization interval Q from the bit rate the same way as the watermark embedding. The received coefficient y is mapped to the nearest multiple of Q. Then the watermark sequence is recovered by

$$y=\begin{cases}1, & d=(2n-1)Q \text{ or } d=(-2n)Q\\ 0, & d=(2n)Q \text{ or } d=(-2n+1)Q,\end{cases} \quad (4)$$
$$n=1,2,3\ldots$$

where d is the distance between the coefficient and the closest quantization point in terms of quantization interval Q. Finally the M consecutive decoded watermark bits are summed and a majority decision rule yields the output bits, which are the decoded watermark.

3. Experimental Results

In this section, the performance of the proposed watermarking scheme to various distortions is demonstrated by experiments on grayscale image. The JPEG2000 codec that is used to test the new watermarking system is Jasper, an implementation of the JPEG2000 encoder/decoder [6]. The objective quality of watermarked image is indicated by PSNR. The robustness under several intentional/unintentional attacks is represented by bit correct ratio (BCR). The 512×512 grayscale image "baboon" is for demonstration here. The testing results for other images show the similar results.

Table 3. Watermark detector results, measured in BCR, with various compression degrees.

f	PSNR without watermark	PSNR with watermark	Capacity (bit)	BCR
1	60.89dB	50.38dB	220	100%
0.625	45.63dB	43.58dB	220	100%
0.5	40.83dB	38.07dB	373	100%
0.25	30.59dB	28.83dB	373	100%
0.1	23.91dB	23.41dB	251	100%

In the experiment, the watermark is embedded into the quantized coefficients of 3HH subband (5 decomposition levels are default for Jasper Codec). The original and watermarked images are shown in Fig. 3. In Table 3, the PSNR (peak-signal-to-noise-ratio) of compressed image with and without watermark as well as watermark embedding capacity (i.e. the maximal number of bits can be embedded) are shown in terms of various compression degrees. The results show that, the new bit-rate adaptive approach is superior to the fixed watermark strength scheme in that the new method takes advantage of the compression to improve the watermark embedding capacity while minimizes the image distortion on top of the compressed images with various bit-rates.

Robustness is tested on four conditions: JPEG baseline, JPEG 2000 compression, additive noise, and low-pass (noise-removal) filtering.

JPEG is widely used for image compression. In the case of JPEG compression with quality factor from 50% to 100%, the BCR is 100% for f=0.1 and nearly 100% for f=0.25 and 0.5. For f=1, the watermark scheme is reliable until the quality factor is smaller than 60%, as shown in Fig. 4(a).

Also we test the watermarked image with JPEG 2000 compression with different bit rate f. The results are shown in Fig. 4(b). For f=1 and f=0.5, the decoded watermark is reliable until the compression bit-rate smaller than 0.5bpp.

Noise is the most common distortion in image processing and transmission. In the experiments, Gaussian noise with variance from 0.01 to 0.05 is added into the watermarked image. As shown in Fig. 4(c), The BCR is about 100% for f=0.1 and 0.25. For f=1 and 0.5, the detected watermark is not reliable when the noise variance is larger than 0.02.

Noise-removal filter is another common attack to the watermarked image. In the experiments, Wiener denoising filter is used to filter the watermarked image with estimated noise variance of 0.01, 0.02, 0.03, 0.04 and 0.05. Refer to Fig. 4(d), the BCR is 100% for f=0.1, around 95% for f=0.5 and 0.25, and 90% for f=0.1.

It can be seen from Fig. 4, the new algorithm is robust to these common attacks and distortions while keeping an acceptable visual quality of the image.

4. Conclusion

In this paper, we presented a compression degree adaptive watermarking method integrated with JPEG2000 image compression standard. Binary watermark is embedded into middle frequency wavelet coefficients after quantization. During image decompression, the watermark is decoded without assistance from either the original image or the reference watermarks. The interval of quantization is designed based on the target bit rate, hence the strength of watermark is proportional to the compression ratio. We point out that, in this way, not only watermark can survive rate distortion, the tradeoff between visual quality and robustness is also balanced. The experiments show that the new algorithm has a good performance in terms of both robustness and fidelity.

5. References

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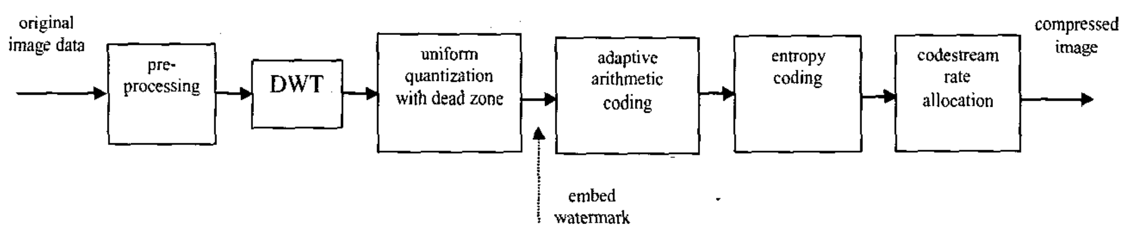

Figure 1: JPEG 2000 fundamental building blocks.

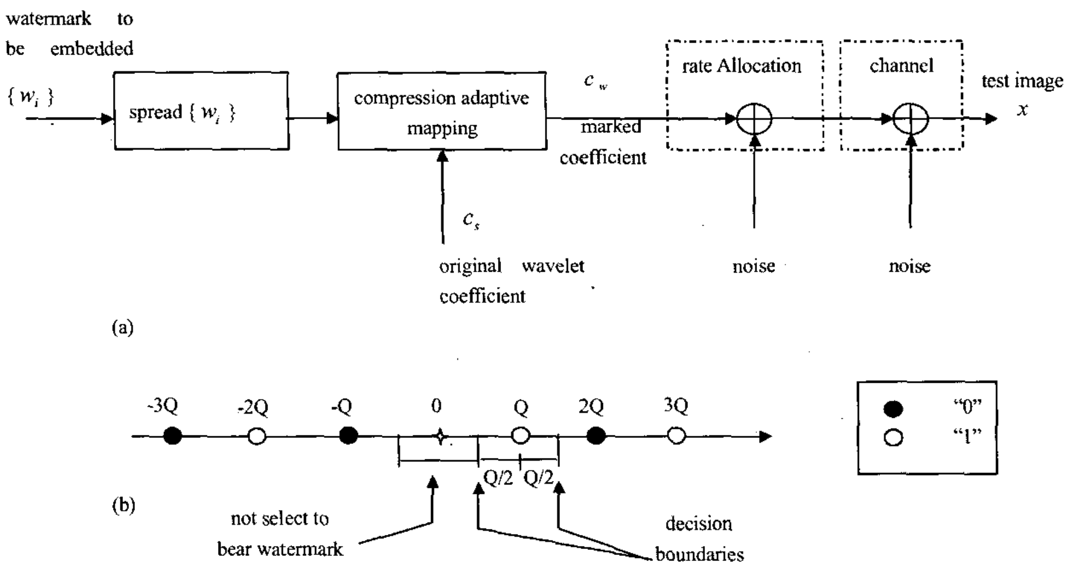

Figure 2: (a) Watermarking in JPEG2000; (b) Watermark encoding/decoding decision boundaries.

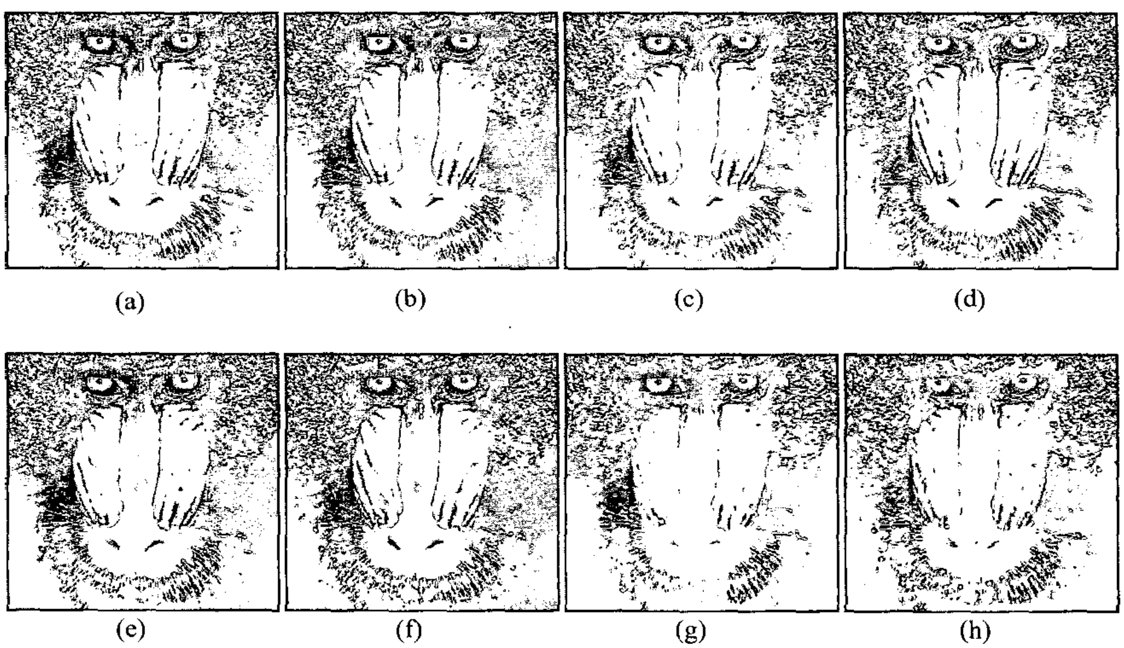

Figure 3. (a)(c)(e) and (g) are JPEG2000 compressed images with bit-rate=1, 0.5, 0.25, 0.1bpp respectively; (b)(d)(f) and(h) are their watermark embedded counterparts respectively. The details are presented in Table 3.

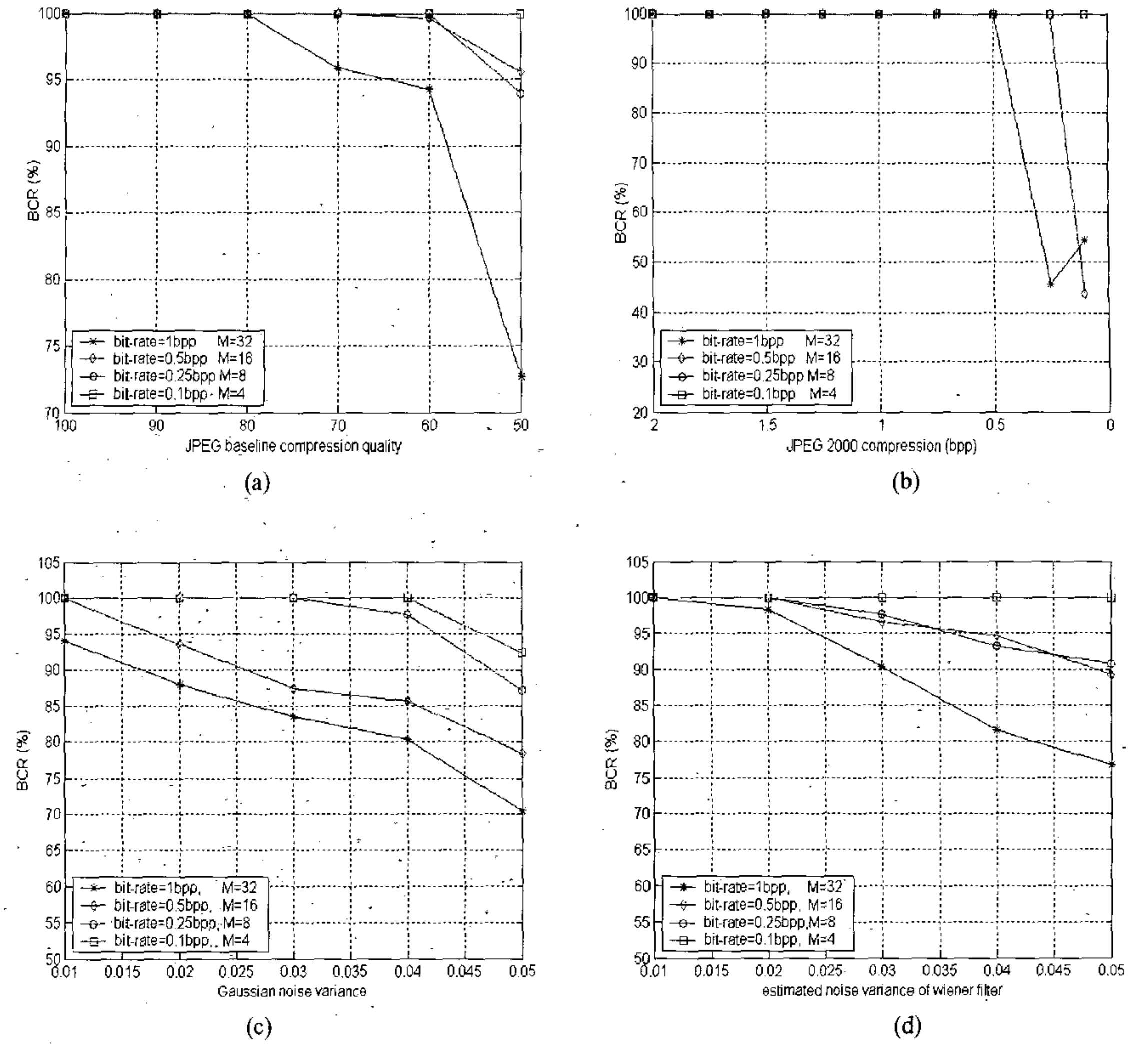

Figure 4. The robustness of watermarked images, which are generated with four different bit-rates, against (a) JPEG baseline compression, (b) JPEG 2000 compression, (c) additive noise, and (d) noise-removal filtering.