Watermarking Experiments Based On Wavelet Transforms

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Abstract

This paper proposes a watermark, W, a set of independent and identically distributed Gaussian pseudo random signals, which is embedded into the coefficients of the high-low band and −W is embedded into those of the low-high band at level 3 in a 3-scale wavelet transform. A watermark generation, insertion, extraction, and verification after a variety of attacks via image operations such as scaling, smoothing, cropping, noise adding, JPEG, SPIHT, and fractal compression, are demonstrated by using Haar and Daubechies' four wavelet transforms on the image *Lenna*. Experiments reporting the PSNR value of each attacked image with its corresponding detected level show that the proposed watermarking strategy is promising.

1 Introduction

As the audio, video, and multimedia products were rapidly distributed over the fast communication systems such as Internet and satellite. The strategies of resolving copyright ownership and verifying the originality of digital contents are urgently requested. Among which watermarking strategies and steganography are alternatively investigated to partially solve the problem. This paper concentrates on the verification of copyright ownership of still images by a watermarking scheme, with a watermark being regarded as a set of random signals which are embedded into an image to protect the copyright of the owner.

A general watermark should be perceptually invisible, robustness to attacks based on signal processing, and resilience to collusion [4, 17]. Cox et al. proposed a watermark as a set of independent and identically distributed (i.i.d.) random floating-point numbers from a Gaussian distribution which were inserted into the most significant N AC coefficients, for example, $N = 1000$, in the discrete cosine transformed (DCT) domain by a multiplicative rule. Podilchuk and Zeng [14] proposed an image-adaptive watermarking scheme by embedding i.i.d. Gaussian pseudo random signals into those significant wavelet coefficients whose magnitudes are greater than their corresponding just noticeable difference (JND) thresholds. Hsu and Wu [6] proposed inserting a binary *logo* into those block DCT coefficients with the middle frequency to protect the image ownership. Wolfgang et al. [17] provided a very good survey of watermarking schemes.

For the existing works of frequency domain approaches, the detection of a watermark is based on checking if a defined similarity index between the extracted watermark and the authorized watermark is significant or not. Both of the above approaches insert watermark into the positions which are generally not the corresponding positions of the extracted watermark. To overcome this drawback, *this paper* proposes inserting the dual i.i.d. Gaussian signals into the high-low band and low-high band at level 3 in 3-scale wavelet transforms. We show the effects of our watermarking scheme based on the transparency; robustness to image operations including

smooth filtering, cropping, scaling, noise adding, JPEG compression, fractal compression, and SPIHT wavelet compression; and the resilience to multiple colluders. The remainder of this paper is organized as follows. Section 2 depicts our watermarking scheme. Section 3 describes an index for a watermark detection and demonstrates the effects of our proposed watermarking scheme based on a variety of experiments. Section 4 gives the conclusion.

2 A Proposed Watermarking Scheme

A general watermarking scheme includes (a) a watermark acquisition, (b) a watermark embedding, (c) a watermark extraction, which have been widely discussed and reviewed by Cox et al. [4], Hartung and kutter [5], Lu and Liao [10], Podilchuk and Zeng [14], Voyatzis and Pitas [16], and Wolfgang et al. [17]. However, more and more experiments need be done to evaluate and validate a watermarking scheme.

2.1 Watermark Acquisition

We propose that a watermark be acquired based on sampling a standard normal distribution $N(0,1)$ by the Box-Muller method with an authorized key as the initial seed.

2.2 Watermark Embedding

Let $\{X(i,j)\}$ be a gray level image of size $N_1 \times N_2$, and let $c_0 = 1/\sqrt{2}$, $c_1 = 1/\sqrt{2}$, define

$$H = \begin{bmatrix} c_0 & c_1 & & & & & & & & \\ c_0 & -c_1 & & & & & & & & \\ & & c_0 & c_1 & & & & & & \\ & & c_0 & -c_1 & & & & & & \\ & & & & \ddots & & & & & \\ & & & & & \ddots & & & & \\ & & & & & & c_0 & c_1 & & \\ & & & & & & c_0 & -c_1 & & \\ & & & & & & & & c_0 & c_1 \\ & & & & & & & & c_0 & -c_1 \end{bmatrix}$$

Then Haar wavelet transform [2] of X can be written as

$$Y \;=\; P \bigotimes\nolimits_4 H \bigotimes\nolimits_3 X \bigotimes\nolimits_1 H^t \bigotimes\nolimits_2 Q \tag{1}$$

where $\bigotimes_j$ is an ordered matrix multiplication, and P, Q are the products of row and column permutation matrices, respectively, for the purpose of downsampling for a coarser wavelet transform. A 3-scale wavelet transform can be depicted as

where $Y_1 = HL_3 = H_{HL3}(X)$ and $Y_2 = LH_3 = H_{LH3}(X)$ are images consisting of wavelet coefficients of high-low and low-high bands at level 3 whose sizes are both $M_1 \times M_2$, where $M_1 = N_1/8$ and $M_2 = N_2/8$, respectively. Let W be a watermark of size $M_1 \times M_2$ which is acquired by sampling $N(0,1)$, a Gaussian distribution with zero mean and unit variance. Our embedding scheme is done pointwise by

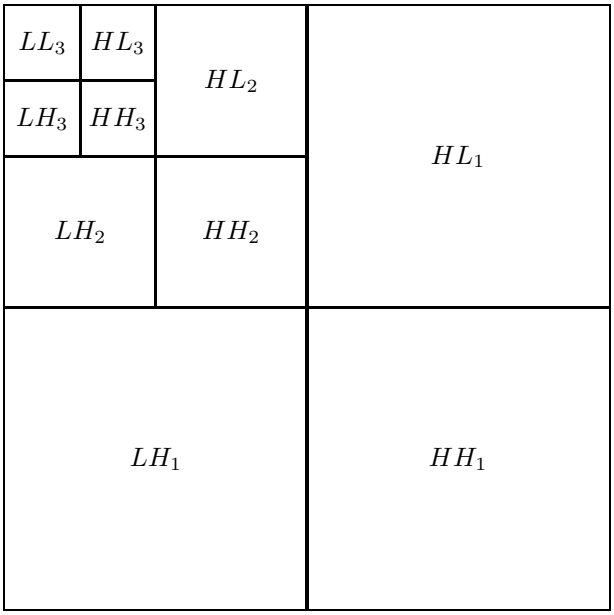

Figure 1: A 3-Scale Wavelet Transform.

$$Y_1 \longleftarrow Y_1 * (1 + \alpha W) \tag{2}$$

$$Y_2 \longleftarrow Y_2 * (1 - \alpha W) \tag{3}$$

where $\alpha \in (0, 0.3]$.

2.3 Watermark Extraction

Let $\{X(i,j)\}$ be the original image of $N_1 \times N_2$, and let $\{W(i,j)\}$ be an authorized watermark, a matrix of $M_1 \times M_2$. Suppose that $\{Y(i,j)\}$ is an observed image of $N_1 \times N_2$, then the extracted watermark W^* can be computed by the following formulas:

$$Z = H_{HL3}(X) \quad or \quad Z' = H_{LH3}(X) \tag{4}$$

$$T = H_{HL3}(Y) \quad or \quad T' = H_{LH3}(Y) \tag{5}$$

$$W^*(i,j) = \frac{1}{\alpha}[T(i,j)/Z(i,j) - 1] \quad or \quad W^*(i,j) = \frac{-1}{\alpha}[T'(i,j)/Z'(i,j) - 1] \quad or \tag{6}$$

2.4 Watermark Detection

To evaluate our proposed watermarking scheme, we adopt the similarity index introduced by Cox et al. [4] which is given below.

$$Sim(W^*, W) = (W^*, W)/\sqrt{(W^*, W^*)} \tag{7}$$

According to a theorem of Probability Theory, $\{W(i,j)\}$ can be treated as a random sample of size K=$M_1 \times M_2$ from $N(0,1)$, and $\{W^*(i,j)\}$ is a set of K numbers, thus, $Sim(W^*,W) \sim N(0,1)$. Therefore, the two-sided confidence interval of $Sim(W^*,W)$ is $[-1.96, 1.96]$, which helps determine the *significance* of the $Sim(W^*,W)$ index or the existence of an extracted watermark.

3 Verification of Watermarks

In the following experiments, we generate a watermark W by assigning an initial seed *5731078*, $\alpha = 0.2$, and then embed this watermark into the high-low and low-high bands at level 3 of a 3-scale Haar wavelet transform on a 512×512 image *Lenna* as shown in Figure 1(a), then do the inverse Haar transform to get a watermarked image *lena0* as shown in Figure 1(b). The original image *Lenna* and an watermarked image *lena0* are perceptually indistinguishable with PSNR=41.29 and Sim=41.95. The remaining of this section will demonstrate the effects of the proposed watermarking scheme under a variety of attacks. We shall report the peak signal-to-ratio (PSNR) value associated with its corresponding similarity index computed by the equation (7) .

3.1 Experiment 1

We run 100 Monte Carlo simulations to randomly generate 100 different watermarks based on randomly assigned seeds to get 100 watermarked images. The 100 Sim indices between each of the 100 extracted watermarks and the authorized one are displayed in Figure 2.

3.2 Experiment 2

This experiment reduces the image *lena0* down to the size 256×256 and enlarge the smaller image back to 512×512 by upsampling and interpolations. Figure 3 shows the attacked image with PSNR=30.46 and the similarity index Sim=2.66.

3.3 Experiment 3

This experiment does smoothing operations with a window size 3×3 on the image *lena0* with the attacked image shown in Figure 4. The PSNR value between Figure 4 and the image *Lenna* is 33.96 and the similarity index between the authorized watermark and the extracted watermark is 3.33.

3.4 Experiment 4

This experiment crops the central 25% of the image *lena0* and is inserted into the image *Lenna* to get an attacked image as shown in Figure 5 with PSNR value and Sim index being 45.95 and 23.17, respectively.

3.5 Experiment 5

This experiment adds independent and identically distributed Gaussian pseudo random signals from $N(0,25)$ into the image *lena0* to get an attacked image as shown in Figure 6 whose PSNR value and Sim index are 33.34 and 3.40, respectively.

3.6 Experiment 6

This experiment tests the effect of DCT/JPEG compression [12]. Figure 7 shows the decoded image of the image *lena0* with the compression ratio 18 (0.444 bits per pixel) by JPEG based on discrete cosine transforms. The PSNR value and Sim index are 32.60 and 3.41, respectively.

3.7 Experiment 7

This experiment tests the effect of fractal compression [1]. Figure 8 shows the decoded image of the image *lena0* with the compression ratio 16 (0.5 bits per pixel) by a fast fractal compression algorithm based on a gradient-match method [3]. The PSNR value and Sim index are 30.51 and 2.91, respectively.

3.8 Experiment 8

This experiment tests the effect of wavelet-based compression [15]. Figure 9 shows the decoded image of the image *lena0* with the compression ratio 16 (0.5 bits per pixel) by the SPIHT wavelet-based compression algorithm [15]. The PSNR value and Sim index are 36.01 and 3.12, respectively.

3.9 Experiment 9

This experiment demonstrates the resilience of our watermarking scheme to multiple colluders. Figure 10 shows an image with 3 watermarks with different seeds are inserted into the image *Lenna*. The PSNR value with *Lenna* is 36.66. The detected watermarks have the Sim indices 23.19, 24.04, and 24.93, respectively.

3.10 Summary

Table 1 summarizes the results of the watermarked image *lena0* as shown in Figure 1(b) under a variety of attacks. The similarity indices between each of the extracted watermarks and the authorized one are all greater than 2.50 which is significantly larger than the randomly selected one whose 95% confidence interval is theoretically [-1.96, 1.96].

Haar	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5	Exp-6	Exp-7	Exp-8
PSNR	41.29	30.46	33.96	45.95	33.34	32.60	30.51	36.01
Sim	41.95	2.66	3.33	23.17	3.40	3.41	2.91	3.12

Table 1: **PSNR and Sim of Watermarked Lenna, lena0, Under Attacks.**

4 Conclusion

We proposed embedding a watermark sampled from a standard normal distribution with a multiplicative rule into the wavelet coefficients of high-low band and low-high band at level 3 of a 3-scale Haar wavelet transform. Simple experiments show that our watermarking scheme satisfies transparency, robustness to a variety of image operations including scaling, smooth filtering, cropping, noise-adding, DCT/JPEG compression, fractal compression, SPIHT wavelet-based compression, and resilience to multiple colluders. Moreover, our scheme avoids the ambiguity of matching the positions of so-called significant transformed coefficients as used in Cox et al. [4] and Podilchuk and Zeng [14]. Our proposed watermarking strategy based on 3-scale Haar

wavelet transforms on the image *Lenna* is promising. Experiments on other images based on other wavelets transforms such as Daubechies' four, and 9/7, 5/3 wavelets [2] merit further studies.

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(a) (b)

Figure 2: (a) Lenna, (b) lena0: A Watermarked Image.

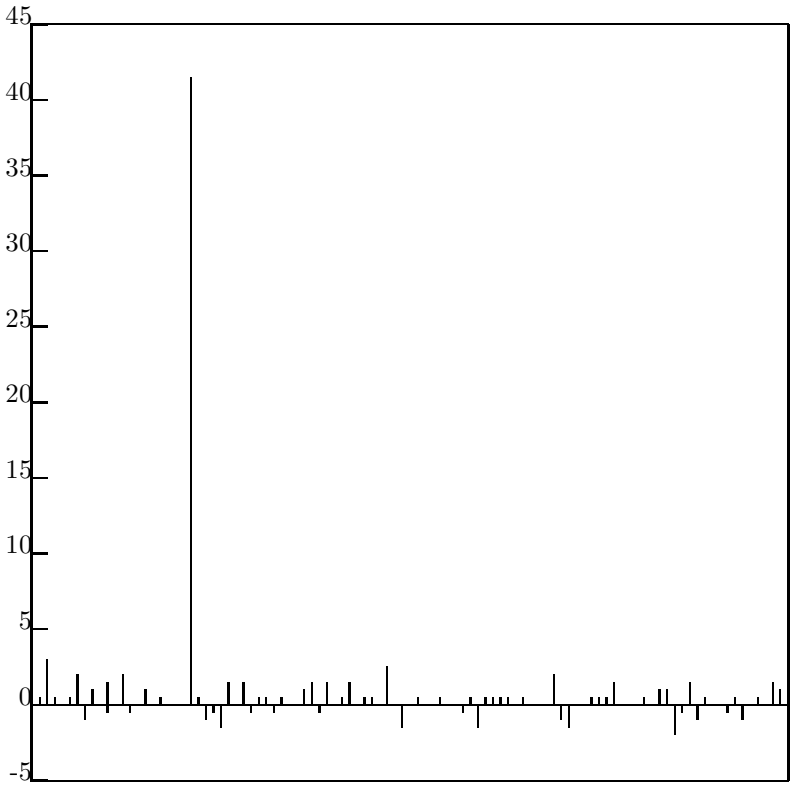

Figure 3: 99 Sim values of random watermarks vs. a true one.

Figure 4: Scaling

Figure 5: Smoothing

Figure 6: Cropping

Figure 7: Noise-Adding

Figure 8: JPEG Compression

Figure 9: Fractal Compression

Figure 10: Wavelet Compression