WAVELET BASED WATERMARKING METHOD FOR DIGITAL IMAGES USING THE HUMAN VISUAL SYSTEM

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ABSTRACT

A wavelet based multiresolution watermarking method using the human visual system (HVS) is proposed, in which a different number of watermarks, in proportion to the energy contained in each band, are embedded into each band. Experiments show that the proposed three-level wavelet based method is robust to various attacks such as joint photographic experts group (JPEG) compression, smoothing, cropping, collusion, multiple watermarking, and so on.

1. INTRODUCTION

With the rapid development of the network multimedia systems, one can easily duplicate digital data. So applying signatures to digital data for author identification is an important issue. Digital watermarking techniques have been proposed in recent years as methods to protect the copyright of multimedia data, which makes it possible to identify the author [1][2]. The watermark should be undeletable, perceptually invisible, statistically undetectable, resistant to lossy data compression and common image processing operations, and unambiguous.

Various watermarking techniques have been proposed over years. In this paper, a multiresolution watermarking method for digital images is proposed based on the discrete wavelet transform (DWT) [3][4]. For enhancement of the visual effect, different weighting [5][6][7] in the DWT band is proposed, according to the characteristic of the modulation transfer function (MTF). In the proposed method, pseudo-random codes are added to the large coefficients which are selected in each frequency band of the DWT domain, with the number of watermarks embedded in each band proportional to the energy in each band.

The rest of the paper is structured as follows. Section 2 describes the watermark insertion process and Section 3 presents the watermark detection process. Experimental results and discussions are shown in Section 4 and conclusions are given in Section 5.

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2. WATERMARK INSERTION

Watermarking in the DWT domain consists of two parts: encoding and decoding. In the encoding part, we first decompose an image into ten bands with a three-level pyramid structure as shown in Fig. 1, in which L (H) denotes the lowpass (highpass) band and the numeric subscript signifies the decomposition level. First, we compute the energy of each band:

$$E = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N} y^2(m,n) \tag{1}$$

where E and MN denote the energy and the size of each band, respectively, and y signifies the DWT coefficient of an image Y.

All the coefficients y are sorted in each band according to the magnitude. Then, the pseudo-random sequence (Gaussian noise) is added to the coefficients [3]. Watermarks are added in seven bands, except for HL_1, LH_1, and HH_1 bands, with the number of inserted watermarks proportional to the energy E in each band:

$$y'(m,n) = y(m,n) + w_i \cdot \alpha \cdot y(m,n)N(m,n) \tag{2}$$

where w_i denotes the HVS weight of the ith band as ex-

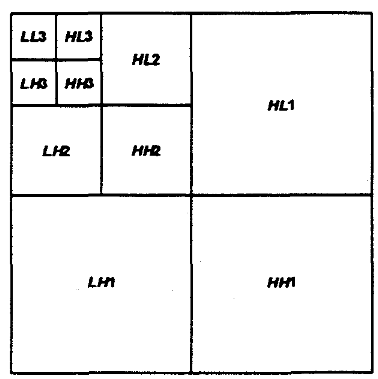


Figure 1. DWT decomposition of an image using three-level pyramid.

pressed in eq. (5), α represents a parameter to control the level of the watermark, $N(m,n)$ denotes a Gaussian noise with zero mean and unit variance, and y' signifies the modified DWT coefficient. Then, we take the two-dimensional (2-D) inverse DWT (IDWT) of the coefficient y', obtaining the watermarked image Y'.

Two parameters are used in our experiments: α_0 for the lowest band LL_3 and α for six remaining bands. A relatively small value is used for LL_3, e.g., α_0=0.01α, in order not to significantly degrade the original image. We do not insert the watermarks into LH_1, HL_1, and HH_1 bands, because the energy in those bands is relatively small. Experimentally, the energy contained in three bands is less than 1% of the total energy, for various test images.

In our experiments, the total number of watermarks is set to 5000, and the number of watermarks inserted in each band except for LL_3 band is determined in proportion to the energy in each band. In the lowest resolution LL_3, the length of the watermark is set to 500.

In order to enhance the invisibility of the watermark, the characteristic of the MTF is used. The MTF $H(f_s)$ is defined as the changing rate of a sinusoidal pattern per subtended visual angle in cycles per degree (CDP), expressed as [5]

$$H(f_s) = p(q + rf_s)\exp(-sf_s)^t \tag{3}$$

where p, q, r, s, and t are constants (in our experiments, p=2.6, q=0.192, r=s=0.114, and t=1.1 are used), and f_s denotes the spatial frequency.

In iterative filter banks, each repetitive application of the half-band highpass filter $g(n)$ is equivalent to the process of corresponding reduction of the filter bandwidth by a factor of two. The bandwidth WB_i of the ith filter is expressed as

$$WB_i = \left(\frac{1}{2^{i+1}}, \frac{1}{2^i}\right) \tag{4}$$

where i denotes the index of the filter.

The sensitivity of the frequency band is defined as the integral of the MTF over the frequency interval in each band, thus the weight of the ith filter bank is defined as

$$w_i = \frac{\int_{WB_i} df_s}{\int_{WB_i} H(f_s) df_s}. \tag{5}$$

After the MTF is constructed in the 2-D frequency domain, each band weight is obtained [6].

3. WATERMARK DETECTION

The extraction of the watermark requires both the original and watermarked images. Given the original image Y and a possibly distorted watermarked image Y^*, we can get a possibly distorted watermark X^* by essentially reversing the steps used to insert the watermark X into Y. If Y^* differs from the watermarked image Y' (through unintentional distortion or active attack), it is highly unlikely that the extracted watermark X^* is identical to the original watermark X. For watermark detection, a similarity measure sim(X, X*) defined by

$$sim(X, X^*) = \frac{X^* \cdot X}{\sqrt{X^* \cdot X^*}} \tag{6}$$

is used [1][2], where '·' denotes the inner product of two vectors.

In our experiments, the three-level DWT is employed, in which an image is decomposed into ten subbands as shown in Fig. 1. Watermarks which are chopped and inserted into seven bands except for LH_1, HL_1, and HH_1 bands are used to obtain the response for watermark detection.

4. SIMULATION RESULTS

Among various test images employed in experiments, the 512 × 512 Bridge image is used to show the effectiveness of the proposed method. Fig. 2 shows the response of the watermark detector to 1000 randomly generated watermarks, among which only one matches the watermark that is actually inserted. In this case, α is experimentally set to 0.15 and α_0=$10^{-2}\alpha$.

Figs. 3(a), 3(b), and 3(c) show the original Bridge image, watermarked image by the proposed method whose detection value is shown in Fig. 2, and the JPEG com-

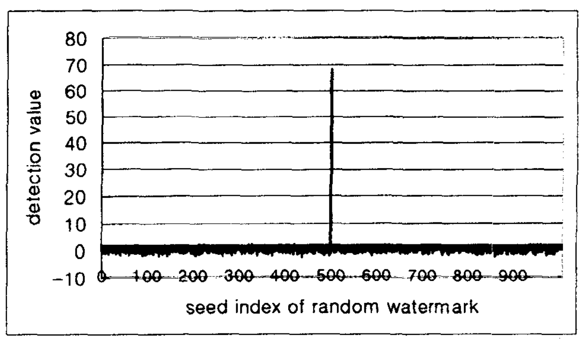
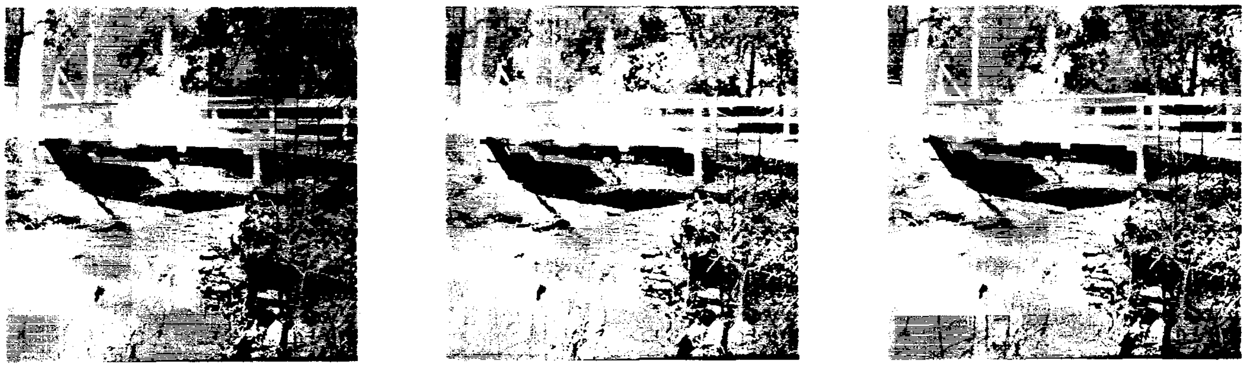


Figure 2. Response of the watermark detector (Bridge).



(a) original image. (b) watermarked image of (a). (c) JPEG image of (b).

Figure 3. Simulation result (Bridge).

pressed image of Fig. 3(b), respectively. The larger the value α, the more the watermarked image degraded.

Fig. 4 shows the response of the proposed method and Cox *et al.*'s method [1] for the watermarked Bridge image, in which 5000 and 1000 watermarks are inserted, respectively. To evaluate the tradeoff between the image quality in terms of the peak signal to noise ratio (PSNR) and peak detection, the PSNRs by the proposed and Cox *et al.*'s methods are adjusted to be comparable with each other, by changing α. Note that the response by the proposed method is much stronger than that of Cox *et al.*'s method.

The peak detection value by the proposed method using the HVS concept is a little bit smaller than that of the method without the HVS concept, however the subjective picture quality is improved.

Watermarks should be resistant to various degradation such as JPEG compression. In experiments, the JPEG compression ratio and the spatial resolution are set to 40 and 300 dots/inch, respectively. Except when α is very small, we can reliably extract the original watermarks.

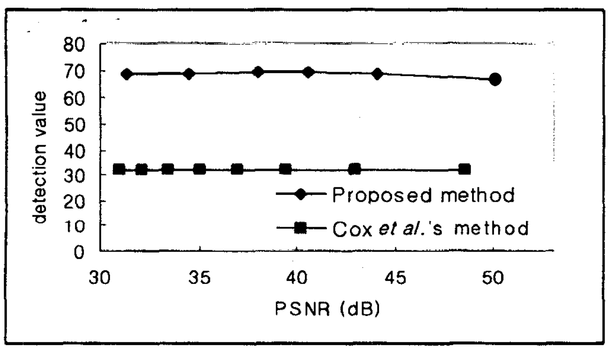


Figure 4. Detection value as a function of the PSNR (Bridge).

When α is very small, the watermarks are lost in JPEG process. Table 1 shows the watermark detection result for JPEG compression cases as a function of α, in which three largest peaks in magnitude are listed to observe the relative reliability of peak detection.

When the watermarked image is filtered by 3×3 averaging, the detection response is relatively lower than that of other attacks, but the proposed algorithm can successfully detect the watermark, which is confirmed by Table 2.

For cropping simulations, the watermarked image is cut from the center, with its size equal to a quarter of the original image size. In order to extract the watermark from the cropped image, the missing background of the image is

TABLE 1 Simulation results (JPEG).

α	First peak	Second peak	Third peak	PSNR
0.05	33.55	3.55	−2.87	30.26
0.10	51.66	−3.32	−3.04	34.45
0.15	58.62	3.62	−3.03	29.92
0.20	63.06	−2.94	2.88	29.64

TABLE 2 Simulation results (smoothing).

α	First peak	Second peak	Third peak	PSNR
0.05	9.83	3.31	−3.16	26.15
0.10	19.87	3.32	−3.19	26.11
0.15	28.49	3.38	−3.31	26.06
0.20	35.39	3.39	−3.36	25.99

TABLE 3 Simulation results (cropping).

α	First peak	Second peak	Third peak	PSNR
0.05	31.60	3.32	−3.32	50.05
0.10	31.84	−3.31	2.97	44.03
0.15	32.76	−3.56	3.37	40.51
0.20	32.64	−3.61	3.28	38.01

TABLE 4 Simulation results (watermarking five times).

α	First peak	Second peak	Third peak	PSNR
0.05	30.12	3.01	2.71	42.61
0.10	30.21	−3.26	3.15	36.87
0.15	30.07	3.46	3.23	33.23
0.20	27.23	4.20	−3.58	30.88

replaced by the original unwatermarked image. Table 3 shows the detected peak value as a function of α for cropping. It is shown that the proposed method can detect watermarks in the image with 75% of the data removed.

Table 4 shows the detection value and the PSNR as a function of α, in which the proposed watermarking method is applied to an image obtained by five successive watermarking operations. Though some attackers may cast the watermarks into the watermarked image, the proposed method can successfully find out the original owner. When α is relatively small, we can detect successfully the watermarks with a high PSNR.

In a similar experiment, we take five separately watermarked images and average them in order to simulate a simple collusion attack. Fig. 5 shows the response of the detector to 1000 randomly generated watermarks, which includes the five watermarks present in the image. Five peaks clearly indicate the presence of the five watermarks embedded and demonstrate that collusion based on simple averaging of a few images is ineffective.

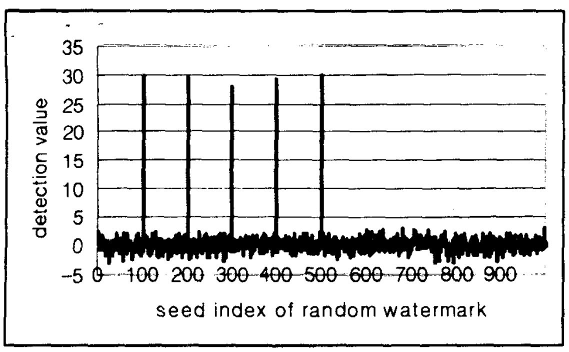


Figure 5. Collusion result (Each of the five watermarks is clearly detected).

5. CONCLUSIONS

A wavelet based watermarking method using the HVS is presented, in which the number of inserted watermarks is proportional to the energy in each band, resulting in the watermarking algorithm robust to various attacks. Employing the multiresolution wavelet based watermarking, the hierarchical characteristics of an image is used in detecting the watermark, i.e., all bands into which we insert the watermarks are considered. The peak detection value by the proposed method using the HVS is a little bit smaller than that of the method without the HVS concept, however the subjective picture quality is improved. Further research will focus on the development of robust watermarking methods not requiring an original image.

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