A Robust Wavelet-Based Digital Watermarking Using Statistical Characteristic of Image and Human Visual System

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Abstract: The current paper proposes a wavelet-based digital watermarking algorithm using statistical characteristic of image and human visual system (HVS). The original image is decomposed into 4-level using a discrete wavelet transform (DWT), then the watermark is embedded into the perceptually significant coefficients (PSCs) of the image. In general, the baseband of a wavelet-decomposed image includes most of the energy of the original image, thereby having a crucial effect on the image quality. As such, to retain invisibility, the proposed algorithm does not utilize the baseband. Plus, the wavelet coefficients on the lowest level are also excluded in the watermark-embedding step, because these coefficients can be easily eliminated and modified by lossy compression and common signal processing. As such, the PSCs are selected from all subbands, except for the baseband and subbands on the lowest level. Finally, using the selected PSCs, the watermark is then embedded based on spatial masking of the wavelet coefficients so as to provide invisibility and robustness. Computer simulation results confirmed that the proposed watermarking algorithm was more invisible and robust than conventional algorithms.

1. Introduction

Digital media, for example, images, audio, and video, can be readily manipulated, reproduced, and distributed over information networks, yet this efficiency has led to problems regarding copyright protection. Therefore, to solve this problem, various digital watermarking algorithms have been investigated. A watermark can contain additional information, such as the identity of the purchaser of a particular copy of the material. However, the development of watermarking algorithms involves certain tradeoffs. A watermark should be robust, i.e., it should survive signal processing. Plus, it should also remain imperceptible and convey as much information as possible. Watermark embedding can be performed in a variety of ways, yet there are two main groups of watermarking algorithms, i.e., spatial-domain algorithms [1],[2] and frequency-domain algorithms [3]-[6]. In the first group, the watermarking algorithms are applied directly to the original data in the spatial domain. As such, spatial-domain algorithms are simple and easily performed, however, they are generally not resistant to lossy compression and common signal processing. In contrast, frequency-domain algorithms are applied in certain transform domains and include transforms such as a block-based discrete cosine transform (DCT), DWT, and other frequency domain representations. Frequency-domain watermarking algorithms are relatively robust to noise, common signal processing, and lossy compression, when compared to spatial-domain algorithms.

Dugad *et al.* [4] proposed an algorithm that adds the watermark to the significant coefficients in the DWT domain. The original image is decomposed into 3-level using a DWT. The algorithm then selects all the coefficients with a magnitude larger than threshold T in all subbands, except for the baseband. The watermark is then embedded in the selected coefficients. Yet, since this algorithm selects the significant coefficients using a fixed threshold, it is not resistant to lossy compression and signal processing.

Podilchuk *et al.* [5] proposed an algorithm using the just-noticeable difference (JND). The original image is decomposed into 4-level using a DWT. The algorithm then selects all the coefficients with a magnitude larger than the JND as the significant coefficients for all subbands, except the baseband, and inserts the watermark into the selected coefficients. However, since this algorithm selects the significant coefficients using a fixed JND in each subband, its robustness is decreased.

Lumini *et al.* [6] proposed an algorithm using a scale parameter determined using the concept of the image local variance. The original image is decomposed into 4-level using a DWT. A threshold is then chosen that is equal to the average value of the wavelet coefficients inside the subbands in level 2 and level 3. The coefficients larger than the threshold are then selected from all subbands in level 2 and level 3 and the watermark embedded into the selected coefficients. As such, the watermark embedding parameter is determined using the concept of the image local variance. However, since this algorithm only uses the average value of the coefficients as the threshold and a fixed watermark embedding parameter in just one image, its robustness is decreased.

Accordingly, the current paper proposes a wavelet-based digital watermarking algorithm using the statistical characteristics of an image and HVS. The original image is decomposed into 4-level using a DWT, then the watermark is embedded into the PSCs in all subbands, except for the baseband and lowest level subbands. The PSCs are selected using the statistical characteristics of the image and a scale factor for each subband. Using the selected PSCs, the watermark is then embedded based on spatial masking of the wavelet coefficients to provide invisibility and robustness. The experimental results confirmed that the proposed algorithm is superior to the conventional algorithms.

2. Proposed Watermarking Algorithm

A digital watermarking algorithm is proposed using the statistical characteristics of an image and the HVS for invisibility and robustness. The original image is decomposed into 4-level using a DWT. Since the baseband of the wavelet-decomposed image includes most of the energy from the original image, it has a crucial effect on the image quality. As such, the proposed algorithm does not utilize the baseband to retain the invisibility. Plus, the wavelet coefficients on the lowest level are also excluded in the proposed algorithm because these coefficients can be easily eliminated and modified by lossy compression and common signal processing. Therefore, the PSCs in all the other subbands, except for the baseband and the subbands of the lowest level, are selected. Using the selected PSCs, the watermark is then embedded based on spatial masking of the wavelet coefficients to provide invisibility and robustness. The embedded watermark is a random signal according to $N(1,0)$ (where $N(\mu,\sigma^2)$ denotes a normal distribution with a mean μ and variance σ^2). The existence of a watermark is calculated based on the similarity between the original watermark and the extracted watermark.

2.1 Selection of PSCs

The mean of the wavelet coefficients is reduced by one half with each descending level. Plus, the mean of the wavelet coefficients in the HH band is only about half that of the LH and HL bands. As such, the scale factor for each subband when selecting the PSCs is determined using the above characteristics. Fig. 1 shows the scale factor for each subband when selecting the PSCs.

The PSCs are determined using a standard deviation and the scale factor for each subband. The steps involved in the selection of the PSCs are:

1. Calculate the standard deviation of each subband
2. Calculate the threshold for each subband, i.e. the standard deviation for each subband is multiplied by the scale factor for each subband.
3. All coefficients in each subband with an absolute magnitude larger than the threshold for that subband are selected as the PSCs.

2.2 Watermark Embedding Using HVS

The PSCs are then modified according to rule [3]

$$v'_{i,j,l} = v_{i,j,l} \times (1 + \alpha_{l,\theta} \times x_{i,j,l}) \quad (1)$$

where $v'_{i,j,l}$ denotes the DWT coefficient of the watermarked image and $v_{i,j,l}$ denotes the DWT coefficient of the original image. $\alpha_{l,\theta}$ is the scaling parameter and $x_{i,j,l}$ is the watermark value. i and j are the position in the each subband. l is the resolution level and θ is the orientation of each subband.

The algorithms of Dugad *et al.* and Lumini *et al.* determine the scaling parameter without considering the characteristic of the wavelet coefficients, thereby decreasing their robustness.

To satisfy invisibility and robustness, the scaling parameter $\alpha_{l,\theta}$ should exploit the masking characteristics of the HVS as regards the wavelet coefficients. Therefore, to provide a better match with the behavior of the HVS when embedding a watermark, the current study uses the model proposed by Lewis *et al.* [7]. In particular, the following considerations are taken into account.

- The eye is less sensitive to noise in high-resolution bands.
- The eye is less sensitive to noise in those bands with an orientation of 45°.

As such, the scaling parameter for each subband is calculated based on these considerations.

$$\alpha_{l,\theta} = A_l \times B_\theta \quad (2)$$

where each term in this equation is explained below.

$$A_l = \begin{cases} 1.00, & if \ l=1 \\ 0.32, & if \ l=2 \\ 0.16, & if \ l=3 \\ 0.10, & if \ l=4 \end{cases} \quad (3)$$

$$B_\theta = \begin{cases} \sqrt{2}, & if \ \theta = HH \\ 1, & if \ otherwise \end{cases} \quad (4)$$

As a result, this approach allows the maximum unperceived watermark level to be embedded in the PSCs, while satisfying both invisibility and robustness. After watermark embedding, the reconstructed image is obtained by performing an inverse discrete wavelet transform. Fig. 2. shows a block diagram of the proposed watermark embedding.

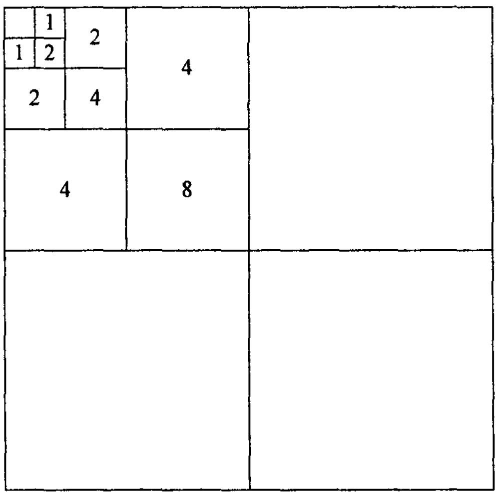

Fig. 1. Scale factor for each subband.

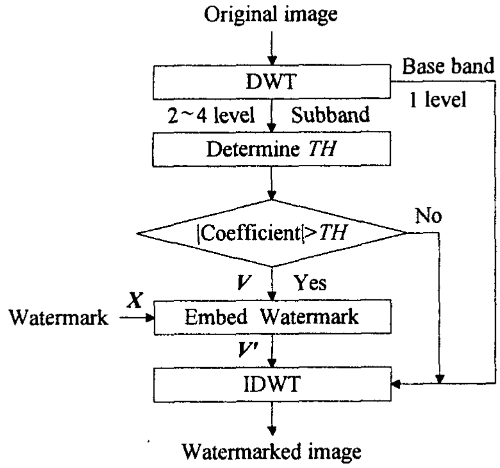

Fig. 2. Block diagram of proposed watermark embedding.

2.3 Watermark Detection

The detection process is the inverse procedure of the watermark embedding process. To extract the watermark, the proposed algorithm requires both the original and the watermarked image. Fig. 3 shows the overall watermark detection process.

To extract the watermark from the watermarked image, the original and watermarked images are decomposed into 4-level using a DWT. Next, the wavelet coefficients of the watermarked image that have PSCs in the same position as in the original image are selected. Since the watermark is the difference between the wavelet coefficients of the original image and the wavelet coefficients of the watermarked image, the PSCs of the original image are then subtracted from the wavelet coefficients of the watermarked image.

Finally, the similarity between the original watermark and the extracted watermark is calculated to detect the existence of a watermark. The similarity will increase or decrease according to the extent of the inserted watermark and the degree of an attack. To calculate the similarity, the proposed algorithm utilizes the following vector projection:

$$sim(X, X^*) = \frac{X \cdot X^*}{\sqrt{X^* \cdot X^*}} \tag{5}$$

where X is the original watermark and X^* is the extracted watermark. However, since the value calculated from equation (5) will change depending on the length of the watermark, another measure of similarity is also used, that is, the normalized version of equation (5). Equation (6) represents the percentage of the remaining watermark after various attacks.

$$sim(X, X^*) = \frac{X \cdot X^*}{\sqrt{X^* \cdot X^*}} \bigg/ \frac{X \cdot X}{\sqrt{X \cdot X}} \times 100 \tag{6}$$

where $\frac{X \cdot X}{\sqrt{X \cdot X}}$ is the self-similarity.

3. Experimental Results

Computer simulations were carried out to demonstrate the performance of the proposed algorithm in which a biorthogonal discrete wavelet transform was used to decompose the original image. The proposed algorithm was applied to test images such as LENA, BARBARA, GOLDHILL, and MAN with a size of 512×512. Invisibility and robustness were used as the performance measures. As such, the PSNR was used as an objective measure of the invisibility, while the normalized similarity denoted by equation (6) was used to measure the robustness.

3.1 Evaluation of the Invisibility

The experimental results demonstrated that the watermarked images were indistinguishable from the original images. As an objective measure of the invisibility, the distortion produced in the original image by the watermark was calculated based on the PSNR. The PSNR results of the watermarked images are summarized in Table I. The proposed algorithm produced a PSNR that was 2.5~7.7 dB higher than those produced with conventional methods.

3.2 Evaluation of the Robustness

To measure the robustness, the normalized similarity was calculated using equation (6) after JPEG compression with various quality factors, the SPIHT algorithm, and a variety of signal processing. In the first experiment, JPEG coding with various quality factors was applied to the watermarked image. As shown by the results plotted in Fig. 4, in this case, the proposed algorithm was found to be robust. Next, the SPIHT algorithm was used to test the robustness of the proposed algorithm against DWT-based compression. As shown by the results summarized in Table II, the proposed algorithm was also robust to the SPIHT algorithm. Finally, the robustness of the proposed algorithm was tested against geometric manipulations, the addition of noise, and a variety of common signal processing. Again, as shown by he results in Table III, the proposed algorithm remained robust against all these attacks. The explanation for these results was that first, the PSCs were determined using the

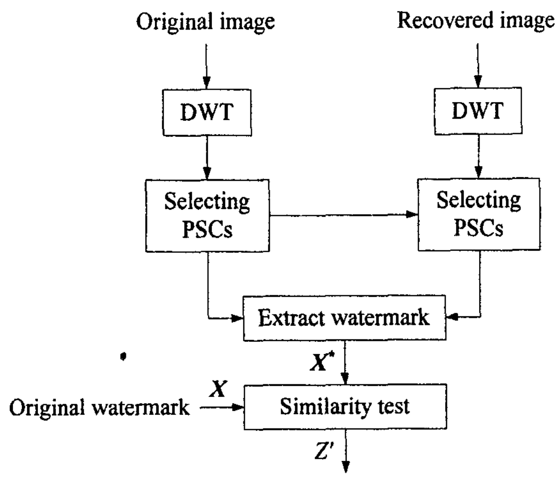

Fig. 3. Block diagram of proposed watermark extraction.

Table I . PSNR [dB] of proposed method and conventional methods.

Images \ Methods	Proposed method	Podilchuk's method	Lumini's method	Dugad's method
LENA	41.25	38.67	36.97	37.97
GOLDHILL	42.70	36.64	34.97	37.61
BARBARA	40.27	35.53	36.59	35.28
MAN	41.26	36.11	34.95	37.14

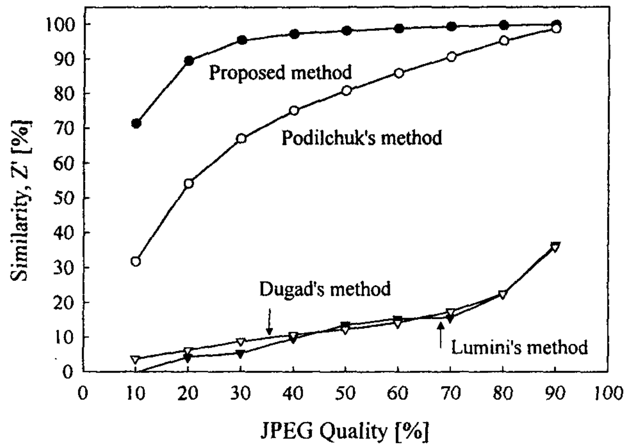

Fig. 4. Normalized similarity [%] according to various JPEG qualities for LENA image.

Table II. Normalized similarity [%] according to various SPIHT bit-rates for LENA image.

Bitrate [bpp]	Proposed method	Podilchuk's method	Lumini's method	Dugad's method
0.05	43.64	5.92	4.19	1.22
0.10	75.47	25.50	8.69	2.75
0.50	98.13	94.18	25.03	19.62
1.00	99.52	98.49	36.91	46.20

standard deviation and scale factor of each subband, and second, in order to embed to PSCs the maximum unperceived watermark level, the watermark was embedded based on the masking characteristics of the HVS of wavelet coefficients.

4. Conclusions

A wavelet-based digital watermarking algorithm was proposed based on the statistical characteristics of an image decomposed into 4-level using a DWT and the PSCs are selected from all subbands, except for the baseband and subbands on the lowest level. Using the selected PSCs, the watermark is then embedded based on spatial masking of the wavelet coefficients so as to provide invisibility and robustness. The similarity between the original watermark and the extracted watermark is calculated to detect the existence of the watermark. Computer simulation results confirmed that the proposed watermarking algorithm was more invisible and robust than conventional algorithms.

Table III. Normalized similarity [%] according to various attacks on LENA image.

Attack	Proposed method	Podilchuk's method	Lumini's method	Dugad's method
3x3 LPF	65.17	35.99	26.02	6.24
5x5 LPF	23.12	10.31	9.56	2.02
3x3 median filter	83.70	53.98	21.75	10.43
5x5 median filter	37.86	17.75	10.21	3.84
Dithering	49.41	22.12	2.26	1.20
Scaling	56.61	34.99	6.01	5.90
Cropping	65.22	67.78	19.30	59.82
1% random noise	96.53	89.20	4.54	23.62
5% random noise	84.12	65.18	2.35	10.25
1% uniform noise	99.96	99.90	13.74	94.42
5% uniform noise	98.99	96.92	4.54	43.06

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