A NEW WAVELET-BASED DIGITAL WATERMARKING USING THE HUMAN VISUAL SYSTEM AND SUBBAND ADAPTIVE THRESHOLD

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Abstract

A wavelet-based digital watermarking algorithm using the human visual system (HVS) and subband-adaptive threshold is proposed in this paper. The proposed algorithm is performed in the WT (wavelet transform) domain by slightly modifying the perceptually significant coefficients in all the subbands excluding them of the lowest level for the robustness to a series of attack. This is because lossy compression such as JPEG and MPEG eliminate the high frequency components. The perceptually significant coefficients for each subband are selected by the subband-adaptive threshold. Then, for each selected coefficient in the high frequency subbands, the maximum amount of the watermark is embedded in the extense of satisfying the invisibility according to the HVS of that coefficient. And the constant amplitude of the watermark is embedded to each coefficient in the baseband considering invisibility. The experimental results show that the proposed algorithm represents the better invisibility and robustness to the attacks than the conventional algorithm.

1. Introduction

Digital media has more advantages for storage, edition, and distribution than analog one. These advantages make possible an illegal copy and modification for digital media. Specially, it is impossible to distinguish the original data from a copied one. So the proliferation of digitized media is creating a pressing need for copyright enforcement schemes that protect copyright ownership. Digital watermarking, one way to protect digital media against illegal manipulation, is to embed a signal called watermark into the data, which characterizes the person who apply it.

Watermark can be embedded either in the spatial[1] or frequency domain.[2]∼[5] Most common approaches in the spatial domain modify the LSB (least significant bits) of an image based on the assumption that the LSB data are insignificant. Schyndel *et al.*[1] proposed two methods of modifying the LSB. However, the watermarking in the spatial domain is highly sensitive to noise and lossy compression while its algorithm is simple and fast. So a watermarking in the frequency domain is popular and common.

Representative method in the frequency domain is the secure spread spectrum proposed by Cox *et al.*.[2] In this algorithm, the watermark is embedded in the largest magnitude DCT (discrete cosine transform) coefficients to provide the greater robustness than LSB-type methods to the compression algorithms. Embedding in the largest coefficients corresponds to placing marks in the most perceptually significant portions of the images so that the portions will remain relatively intact when subjected to the lossy compression. This algorithm can be resulted in a poor image quality because of manipulating the most perceptually significant portion of the images. Also it is sensitive to the noise, image processing, and geometric transformation while it is robust to the lossy compression.

Recently, watermarking algorithms using WT[3]∼[5] have been introduced as alternative frequency domain watermarking algorithms. Generally, the baseband has most energy of the image and crucial effect on the image quality. So, since most of them do not utilize the baseband to preserve the image quality, they are not robust to the lossy compression. Consequently, the development of a new algorithm that can satisfy both the invisibility and the robustness is needed.

The current study proposes a wavelet-based digital watermarking algorithm using the HVS and subband-adaptive threshold. In the proposed method, the information on the lowest level is excluded in the watermarking embedding step as this information can be easily eliminated and mod-

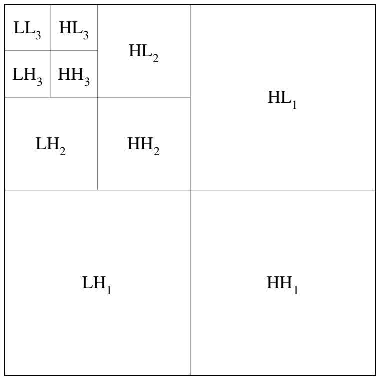

Figure 1: 3-level wavelet decomposition.

ified by lossy compression. For the watermark embedding step, the perceptually significant coefficients are selected by each subband-adaptive threshold, then a watermark is embedded maximally into these coefficients based on the HVS[5],[6] to satisfy the robustness. The watermark is created consist of a sequence of real number according to the normal distribution. In the watermark extracting step, the authenticity of the watermark in the recovered image can be examined by measuring the similarity between the original and the extracted watermark based on a vector projection method.

In computer experiment, we tested the invisibility of the watermark and the robustness by subjecting the watermarked image to a series of attacks. The proposed algorithm is more invisible and robust than the conventional algorithm.

2. Proposed watermarking method using the HVS in the WT domain

Generally, a watermarking algorithm needs the invisibility and robustness. But it is in the trade-off relationship between the invisibility and robustness. Therefore, a new watermarking algorithm satisfying the invisibility and robustness simultaneously is required.

We proposed a wavelet-based digital watermarking using the HVS and subband adaptive threshold. WT reveals multiresolution characteristic that is similar to the HVS and also efficiently localizes an image for both the spatial and frequency domain. So it has been widely used in image processing and compression. In the proposed algorithm, an image is decomposed into 3-level as shown in Fig. 1, and three subbands in the lowest level (HL_1, LH_1, and HH_1) represent high frequency components so that these are excluded in the embedding step for the robustness to the lossy compression. Then the perceptually significant coefficients are selected in other subbands and the watermark is embedded for these coefficients.

(a) (b)

Figure 2: The perceptually significant coefficients of (a) LENA and (b) GIRL.

2.1. Determination of the subband adaptive threshold

To select the perceptually significant coefficients, a subband-adaptive threshold is used as follows

$$TH_i = 2^{\lfloor \log_2 C_i \rfloor - 1} \tag{1}$$

where C_i represents the largest coefficient in each subband and $\lfloor X \rfloor$ represents the largest integer which is no greater than X. The watermark is embedded only to the perceptually significant coefficients greater than the subband adaptive threshold. The perceptually significant coefficients for LENA and GIRL image are represented in Fig. 2.

2.2. Embedding watermark using the HVS

Embedding watermark in the selected coefficients follows two different ways whether they are located in the baseband or high frequency bands. The watermark is embedded using

$$v_i^{'} = v_i \times (1 + w_i \times x_i) \tag{2}$$

where $v_i^{'}$, v_i, w_i, and x_i represent watermarked coefficient, original coefficient, weighting factor, and watermark respectively. The algorithm proposed by Cox et al. use a constant w_i regardless of the visual importance of the corresponding coefficients. To overcome this problem, we use a constant w_i for the coefficient in the baseband, which is the largest value in the extense of not introducing visual artifact, and various w_i based on the HVS for the coefficient in the high frequency bands. Baseband has a crucial effect on the image quality so that invisibility and robustness are considered in embedding the watermark. In this paper, we used weighting factor of 0.02.

For the coefficients in the high frequency bands, the watermark is embedded maximally according to HVS for the robustness to various attack and invisibility. The HVS for the wavelet coefficient is followed:

1. The eye is less sensitive to noise in high resolution bands and in those bands having orientation of 45 °. (A_i)

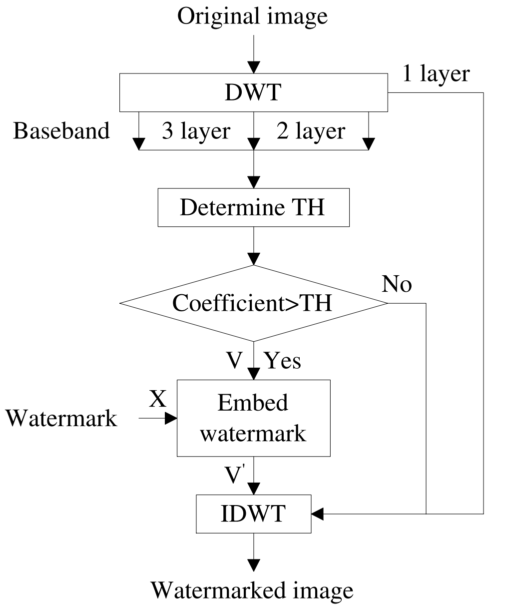

Figure 3: *The block diagram of the proposed watermark embedding.*

2. The eye is less sensitive to noise in those areas of the image where brightness is high. (B_i)

Based on the above considerations we use the weighting factor in the high frequency bands as

$$w_i = A_i \times B_i. \tag{3}$$

A_i has more larger value in the lower level, and in the LH and HL bands than HH band. B_i corresponds to the local brightness based on the corresponding gray level values of the baseband. They are mathematically represented by

$$A_i = \begin{cases} \sqrt{2} & if\ \theta = HH \\ 1 & otherwise \end{cases} \begin{cases} 0.32 & if\ l = 1 \\ 0.16 & if\ l = 2 \end{cases} \tag{4}$$

$$B_i = I^{LL_3}\left(\tfrac{i}{2^{3-l}}, \tfrac{i}{2^{3-l}}\right) \tag{5}$$

where l and θ respectively represent the level and orientation and i and j respectively represent the vertical and horizontal index in which the coefficients are located. By embedding the watermark considering HVS, we can infer that the invisibility and robustness is satisfied. After the watermark is embedded in different ways according to the baseband and high frequency bands, the watermarked image is obtained through the inverse WT. Fig. 3 represents block diagram of the proposed watermark embedding procedure. The watermark used in the embedding step is a random sequence with a normal distribution having zero mean and unity variance. The choice of a normally distributed watermark is motivated by the attempt to achieve

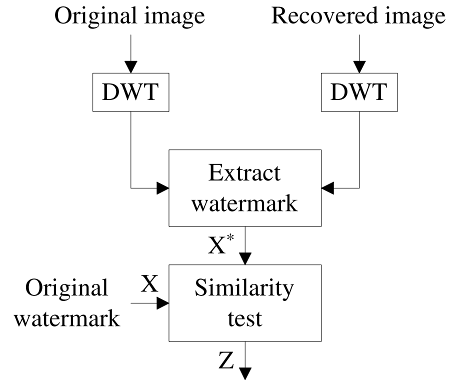

Figure 4: *The block diagram of the proposed watermark extracting.*

robustness against the attacks performed by trying to produce an unwatermarked image by averaging multiple differently watermarked copies of it.

2.3. Extraction of the watermark

Watermark extraction step is similar to the inverse of the embedding procedure. The original and recovered image are decomposed into 3-level through the WT. The perceptually significant coefficients are selected for the coefficients of the original image and the coefficients with the same frequency component in the recovered image are selected as the perceptually significant coefficients for the recovered image. The watermark is extracted by subtracting the selected coefficients in the original image from those in the recovered image. Then to verify the existence of the original watermark in the recovered image, the similarity between original watermark and extracted one is calculated by

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

where X and X^* represent respectively the original and extracted watermark, $\langle \cdot \rangle$ is inner product of vectors. The existence of the original watermark in the recovered image is determined by comparing similarity value with a threshold. Fig. 4 shows the block diagram of the watermark extracting.

3. Experimental results

In order to evaluate the proposed watermarking scheme, we took LENA and GIRL image of size 256×256 and produced the watermarked version, and then subjected the watermarked image to a series of image processing and geometric transformation. The biorthogonal discrete WT was

(a) (b) (c)

Figure 5: *(a) Original LENA image and watermarked images by (b) Cox's method (37.3 [dB]) and (c) proposed method (37.7 [dB]).*

(a) (b) (c)

Figure 6: *(a) Original GIRL image and watermarked images by (b) Cox's method (40.3 [dB]) and (c) proposed method (41.5 [dB]).*

used to decompose the original image into 3-levels. The equal length of the watermark used in the algorithm proposed by Cox et al., 1000 are used by varying a threshold in the baseband. The performance measure is the invisibility and the robustness. The PSNR and similarity are the metric of the invisibility and robustness respectively.

3.1. Invisibility

The watermark is almost invisible to the human eyes as shown in Fig. 5 and Fig. 6 which show the original and watermarked image by both the proposed algorithm and the Cox et al.'s algorithm for LENA and GIRL image respectively. The proposed method from this figure is superior to the Cox et al.'s method. This result is caused by the proposed embedding algorithm which exploits the HVS for the invisibility.

3.2. Robustness

To verify the robustness of the proposed algorithm, we subjected the watermarked image to JPEG coding, image processing, and geometric transformation. Fig. 7 shows the robustness for JPEG coding at various qualities. This figure represents the proposed algorithm is more robust than Cox et al.'s algorithm, especially for the LENA image at the high compression ratio. The robustness to the image processing and geometric transformation is shown in Table I. From this table, it is shown that the proposed algorithm is more robust except to the cropping.

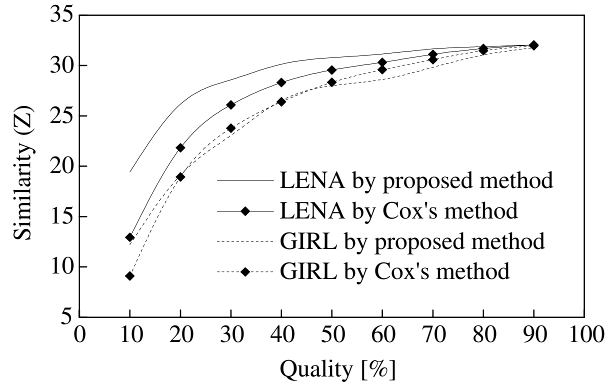

Figure 7: *The similarity according to various JPEG quality.*

Table I. The similarity according to various attacks.

Attack	LENA		GIRL	
	Proposed method	Cox's method	Proposed method	Cox's method
3×3 LPF	19.00	13.28	16.49	16.44
5×5 LPF	9.31	4.33	7.88	5.93
3×3 median	15.06	6.70	14.44	7.63
5×5 median	6.65	2.58	5.69	3.21
Dithering	10.59	8.96	4.78	6.71
Scaling	15.54	9.25	14.86	12.09
Cropping	19.12	20.19	17.57	18.39
Noise	11.03	6.55	7.27	4.60

The proposed watermarking algorithm embed the watermark having maximum amplitude into the perceptually significant coefficients of DWT using the HVS. So it is robust to the JPEG coding, image processing, geometric transformation, and noise.

4. Conclusions

In this paper, a new digital watermarking algorithm using WT is proposed. The proposed watermarking method improves the performance in terms of the invisibility and the robustness, by using the human visual system and subband adaptive threshold. The perceptually significant coefficients is selected by using the subband-adaptive threshold and the watermark is embedded to them exploiting the HVS. The watermark is extracted by the inverse procedure of the embedding step and the similarity between the original and extracted watermark to verify the existence of the original watermark in the recovered image.

The proposed method has been verified to be superior to conventional method for the invisibility of the watermark and the robustness to a series of attack.

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