Wavelet-Based Robust Digital Watermarking Considering Human Visual System

Manabu Shinohara, Fumiaki Motoyoshi
Graduate School of Engineering
Tokai University
1117 Kitakaname, Hiratsuka, Kanagawa
JAPAN

Osamu Uchida, Shohachiro Nakanishi
Dept. Human and Information Science
Tokai University
1117 Kitakaname, Hiratsuka, Kanagawa
JAPAN

Abstract: - In recent years, there have been many studies of digital watermarking as one of the way to protect the copyrights of digital content. It is required for digital watermarking method that the watermark is perceptually invisible and robust against various kinds of attacks. In this paper, we propose a digital watermarking method based on the noise masking effects and the HVS (human visual system). Experimental results show that the watermark embedded by the proposed method is perceptually invisible and robust against various attacks such as JPEG compression and adding noise.

Key-Words: - Digital watermarking, Wavelet transform, Human visual system, Noise masking effects, Perceptual weighting function

1 Introduction

By reason of the rapid spread of computer networks as represented by the Internet, the technology of copyright protection for digital contents has become increasingly important, because we can easily made identical copies of digital contents. Against this background, the data hiding technologies for digital data such as digital watermarking have gotten a lot of attention recently [1][2][3][4][5]. In this paper, a digital watermarking method for still images based on the discrete wavelet transform (DWT) is proposed. Our method selects the DWT coefficients to embed the watermark by considering the noise masking effects [6][7], and embeds the watermark weighted by the function of the characteristics of the human visual system (HVS) [8]. Experimental results show that the watermark embedded by the proposed method is perceptually invisible and robust against various attacks.

2 Watermark Embedding

2.1 Wavelet transform and noise masking effects

The image to be watermarked is first decomposed through the DWT in 3-levels. Let us call W_l^θ the subband at resolution level $l = 0,1,2$ and with orientation $\theta \in \{0,1,2,3\}$ (See Fig. 1). In the proposed

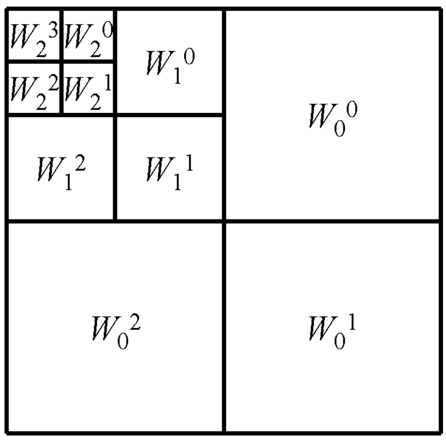

Fig. 1. Decomposition of an image in three resolution levels through the DWT.

method, the DWT coefficients to be watermarked are selected by considering the noise masking effects. Let us define the block of the coefficients for embedding the watermark $V^\theta(i, j)$ by

$$V^\theta(i, j) = \{W_1^\theta(2i+u, 2j+v) \mid u, v = 0,1\}. \quad (1)$$

Next, we define the block of the coefficients for embedding determination $A^\theta(i, j)$ by

$$A^\theta(i, j) = \{W_0^\theta(4i+u, 4j+v) \mid u, v = 0, \cdots, 3\}. \quad (2)$$

If the values of the coefficients in $A^\theta(i, j)$ are large, the domain of the host image corresponding to

$A^\theta(i,j)$ can be presumed as complex area. However, if the values of the coefficients around the block $A^\theta(i,j)$ are small, the area of the host image corresponding to $A^\theta(i,j)$ might be the domain with edges [7]. The watermark should not be embedded into such area because it is known that the eye is sensitive near the edges. Therefore, in the proposed method, the values of the coefficients of the left, right, top and bottom segments of $A^\theta(i,j)$ are also considered to determine whether the domain of the host image corresponding to $A^\theta(i,j)$ is embedding domain or not. Consequently let us define

$$a[A^\theta(i,j)] = \sum_{W_0^\theta(x,y)\in A^\theta(i,j)} \left|W_0^\theta(x,y)\right|, \quad (3)$$

and if the all the values of $a[A^\theta(i,j)]$, $a[A^\theta(i,j-1)]$, $a[A^\theta(i-1,j)]$, $a[A^\theta(i+1,j)]$, $a[A^\theta(i,j+1)]$ are larger than the threshold α, the area of the host image corresponding to $A^\theta(i,j)$ is determined as the watermarking domain.

2.2 Weighting function based on HVS

In order to strengthen the robustness to attacks, we apply the weighting function based on the human visual system to watermark. In [8], Barni et al. introduced perceptual weighting function based on the following three considerations.

- The eye is less sensitive to noise in high resolution bands, and in those bands having orientation of forty-five degree (i.e., $\theta = 1$ in our case).
- The eye is less sensitive to noise in those areas of the image where brightness is high or low.
- The eye is less sensitive to noise in highly textured areas but, among these, more sensitive near the edges.

In our method, as the watermarking areas are selected by considering the noise masking effects, that is, the domains to be watermarked are selected by considering the third consideration, the function considering only the first and the second consideration is adopted as perceptual weighting function. The weighting function $q^\theta(i,j)$ is defined by

$$q^\theta(i,j) = \Theta(\theta)\Lambda(i,j), \quad (4)$$

where

$$\Theta(\theta) = \begin{cases} \sqrt{2}, & \theta = 1 \\ 1, & \text{otherwise} \end{cases}, \quad (5)$$

which is derived from the first consideration, and

$$\Lambda(i,j) = \begin{cases} 1.5 - L(i,j), & L(i,j) < 0.5 \\ 0.5 + L(i,j), & \text{otherwise} \end{cases}, \quad (6)$$

where

$$L(i,j) = \frac{1}{256} W_2^3(i,j). \quad (7)$$

2.3 Embedding algorithm

In our method, the watermark is embedded by using the correlation between the wavelet coefficients of the block $V^\theta(i,j)$ and the parent of these coefficients, that is, $W_2^\theta(i,j)$. The embedding algorithm of the proposed method is as follows;

Step1: We calculate the wavelet coefficients $W_l^\theta(i,j)$ of the host image.

Step2: We divide the coefficients of W_1^θ into the block $V^\theta(i,j)$. Next we determine whether $V^\theta(i,j)$ is the embedding block or not for all blocks. If the all the values of $a[A^\theta(i,j)]$, $a[A^\theta(i,j-1)]$, $a[A^\theta(i-1,j)]$, $a[A^\theta(i+1,j)]$, $a[A^\theta(i,j+1)]$ are larger than the threshold α, the block $V^\theta(i,j)$ corresponding to the parent of $A^\theta(i,j)$ is determined as the watermarking block. If we can not gain the necessary blocks to embed the watermark information, we repeat this process by dwindling the threshold α. Moreover, we stored the coordinates of the block determined as the watermarking block, because we need these coordinates as the key when we detect the watermark.

Step 3: We embed the watermark $b_n \in \{0,1\}$ by the following method;

(a) the case of $b_n = 1$:

If

$$W_2^\theta(i,j) + Sq^\theta(i,j) > v[V^\theta(i,j)] \quad (8)$$

holds, where

$$v[V^\theta(i,j)] = \sum_{W_1^\theta(x,y)\in V^\theta(i,j)} W_1^\theta(x,y), \quad (9)$$

and S represents the watermark strength, then we let

$$W_1^{\theta}(x,y) = W_1^{\theta}(x,y) + \frac{W_2^{\theta}(i,j) + Sq^{\theta}(i,j) - v[V^{\theta}(i,j)]}{4} \qquad (10)$$

for all $W_1^{\theta}(x,y) \in V^{\theta}(i,j)$. If the equation (8) does not holds, we do not change the values of $W_1^{\theta}(x,y) \in V^{\theta}(i,j)$.

(b) the case of $b_n = 0$:

If

$$W_2^{\theta}(i,j) - Sq^{\theta}(i,j) < v[V^{\theta}(i,j)] \qquad (11)$$

holds, then we let

$$W_1^{\theta}(x,y) = W_1^{\theta}(x,y) - \frac{v[V^{\theta}(i,j)] - W_2^{\theta}(i,j) + Sq^{\theta}(i,j)}{4} \qquad (12)$$

for all $W_1^{\theta}(x,y) \in V^{\theta}(i,j)$. If the equation (11) does not holds, we do not change the values of $W_1^{\theta}(x,y) \in V^{\theta}(i,j)$.

Step4: We get the embedded image by the inverse discrete wavelet transform.

3 Watermark Detection

The detection algorithm of the proposed method is as follows;

Step1: We calculate the wavelet coefficients $\tilde{W}_l^{\theta}(i,j)$ of the embedded image.

Step2: We determine the watermarked block using the key.

Step3: We detect the watermark information by the following rule;

$$b_n = \begin{cases} 1, & v[V^{\theta}(i,j)] \geq \tilde{W}_2^{\theta}(i,j) \\ 0, & \text{otherwise} \end{cases}, \qquad (13)$$

4 Experimental Results

In this section, we show some experimental results to show the perceptual quality and the robustness against JPEG compression and adding Gaussian noise. We embed 256 bit watermark information into three color standard images "Lenna", "Girl" and "Mandrill" of 256×256 pixels. In these experiments, the watermark is embedded into Y component of each images.

Fig. 2 shows the original images and the watermarked images using the proposed method with the parameter $S = 5$. From these results, it can be said that the watermark embedded by the proposed method is perceptually invisible.

(a) original "Lenna" (b) watermarked "Lenna"

(c) original "Girl" (d) watermarked "Girl"

(e) original "Mandrill" (f) watermarked "Mandrill"

Fig. 2. Original and watermarked images.

Next, we evaluate the performance of the proposed method against JPEG compression and the adding Gaussian noise. Fig. 3 shows the bit error rate for JPEG compression. This indicates that in the case where the quality of JPEG compression is 80 the bit error rate is almost equivalent to zero. Therefore, it can be said that the proposed method is robust against usual JPEG compression ratio. Moreover, we evaluate the robustness of our method for the adding Gaussian noise. Fig. 4 shows the bit error rate for the adding Gaussian noise where the horizontal axis represents the variance of Gaussian noise. This shows that our method can be said as having the robustness against the adding Gaussian noise attack.

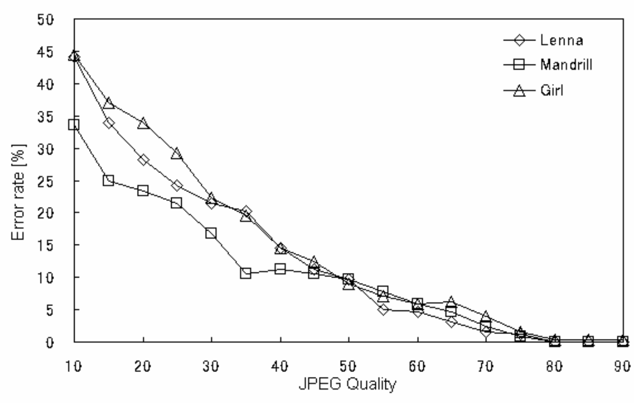

Fig. 3. Bit error rates after JPEG compression.

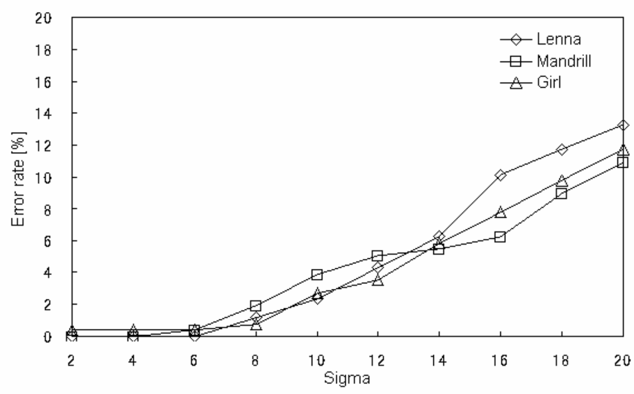

Fig. 4. Bit error rate after adding Gaussian noise.

5 Conclusion

In this paper, a wavelet-based digital watermarking method for still images based on the noise masking effects and the HVS (human visual system) has been presented. We confirmed that the watermark embedded by the proposed method is perceptually invisible and robust against various attacks.

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