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An Image Digital Watermarking Method Embedding Self-Orthogonal Finite-Length Sequences into Wavelet Domain

Shuhong Li[1]   Yoshihiro Tanada[2]
1. Department of Computer Science, Henan Institute of Finance and Economics
No. 80, WenHua Road, Zhengzhou, Henan, 450002 P.R.China
Tel: +86-371-63752670, E-mail: lshuh@tom.com
2. Department of Computer Science and Systems Engineering，Yamaguchi University
2-16-1 Tokiwadai, Ube, Yamaguchi, 755-8611 Japan
Tel: +81-836-85-9506, Fax: +81-836-85-9501
E-mail: tanada@ca.csse.yamaguchi-u.ac.jp

Abstract: - The growth of new image technologies has created a need for techniques that can be used for copyright protection of digital images. One approach for copyright protection is to introduce an invisible signal known as a digital watermark in the image. In this paper a watermarking algorithm operating in the wavelet domain is presented. The watermarks are two-dimension self-orthogonal finite-length sequences which are embedded in the middle frequency wavelet coefficients. Watermark detection is accomplished without the original image by computing the correlation between the watermarked coefficients and the watermarking code. Experiment results demonstrate that the proposed watermarking scheme is perceptual invisible and robust against attacks such as JPEG compression，additive noise and filtering.

Key-Word: - Image watermarking, Wavelet transform, Self-orthogonal finite-length sequences, Correlation detection, JPEG compression.

1. Introduction

With the increase of the availability of digital data such as multimedia services on the internet, there is a pressing need to manage and protect the illegal duplication of data. One approach to address this problem involves adding an insensible structure to a host data to mark ownership of it. These structures are known as digital watermarks. To be effective, a watermark must be imperceptible within its host, discrete to prevent unauthorized removal, easily extracted by the owner, and robust to incidental and intentional distortions.

In this paper we address the watermarking of still image data. There are many benefits of embedding a watermark in an image. The digital watermark can be used as an authentication tool, and as a method to discourage the unauthorized copying and distribution of electronic documents. Most of the recent works can be grouped into two categories: spatial domain methods, and frequency domain methods. Spatial domain watermarking is easy to implement and requires no original image data for watermark detection. However, it often fails under signal processing attacks such as filtering and compression. Besides, the fidelity of the original image data can be severely degraded since the watermark is directly applied on the pixel values [1]. Frequency domain watermarking generally provides more protection under most of the signal processing attacks. But most of the existing frequency-domain watermark algorithms require the original image for comparison in the watermarking retrieval process, which is not practical for a huge image database [2].

To solve the above problems associated with existing watermarking algorithms, we propose a wavelet-based watermarking approach. The proposed method uses self-orthogonal finite-length sequences as watermarks to be embedded into the middle frequency subbands. Besides, a blind watermark retrieval algorithm can be applied. Experimental results show that the proposed algorithm is robust to JPEG compression, additive noise and two-dimension filtering attacks.

In the next section we introduce the proposed approach. In Section 3 we provide some results demonstrating the high robustness of the approach to JPEG compression, additive noise and two-dimensional filtering. Finally, concluding remarks are provided in Section 4.

2. Proposed Watermarking Scheme

2.1 General Description

The proposed method employs a multi-resolution wavelet decomposition of the host image in Fig.1. Because of the characteristics of the human visual system, if the watermark is embedded in the low frequency subband as LL_2 the quality of the image will be degraded. And if the watermark is embedded in the high frequency subband as HH_1 it will be removed easily by the low-pass filtering. So in this paper the watermarks are embedded into the middle frequency subbands LH_2 and HL_2.

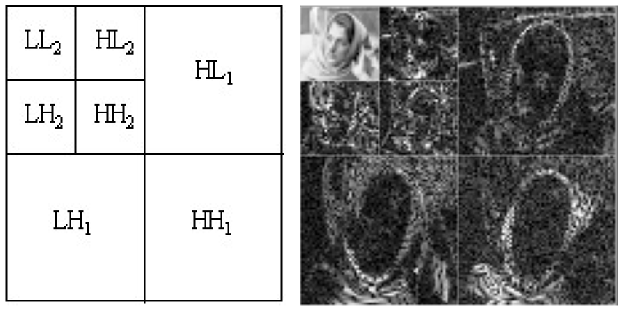
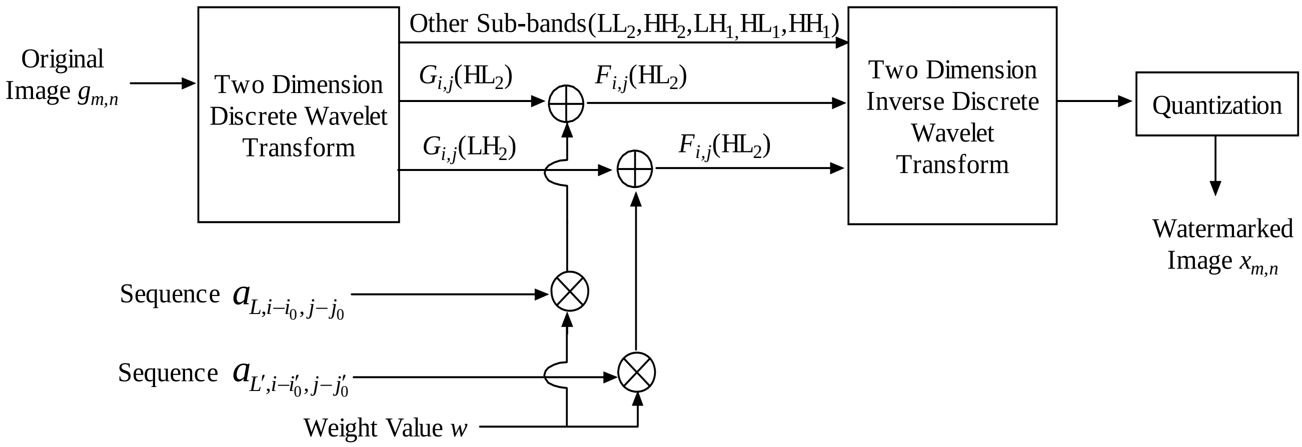


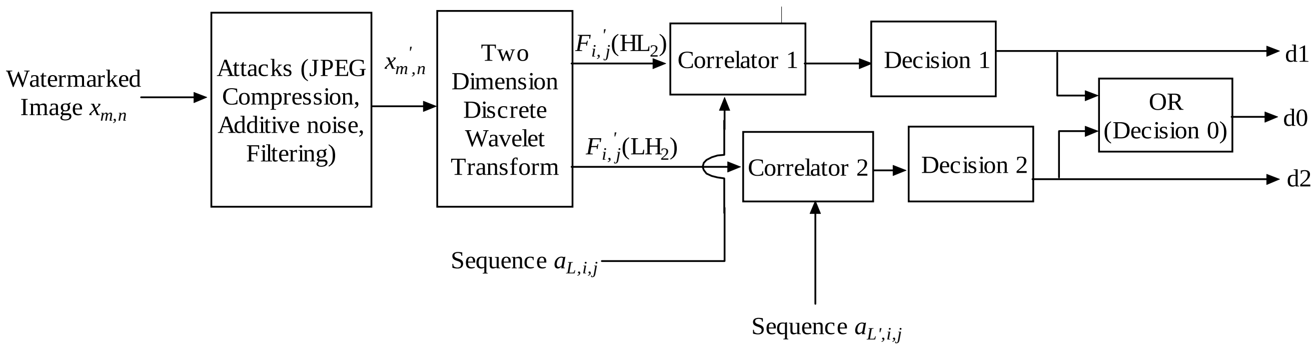
Fig.1 Wavelet decomposition of image.

The block diagrams of watermark embedding process and detection are shown in Fig.2. In the watermark embedding process, firstly we use 2-level wavelet transform to the original image to obtain the subbands LH_2 and HL_2. Then two-dimension self-orthogonal finite length sequences $a_{L,i-i_0,j-j_0}$ and $a_{L',i-i'_0,j-j'_0}$ are embedded into the appropriate positions of the subband images LH_2 and HL_2 separately after multiplying the weight value w. Finally the inverse wavelet transform is used to obtain the watermarked image. The size of sequences is smaller than the size of subbands LH_2 and HL_2. We can choose the weight value w to make sure of the peak signal-to-noise ratio (PSNR) of the watermarked image.

In the watermark detection process the original image is not needed and we can determine whether the watermark is present or not by the correlation operation. We can detect the watermark signal with the magnitude proportional to the weight value w.



(a)



(b)

Fig.2 Block diagrams for the proposed watermarking scheme. (a) Watermark embedding. (b) Watermark detection.

2.2 Self-Orthogonal Finite-Length Sequence

The watermarks in this paper are two-dimension self-orthogonal finite-length sequences. First we introduce one-dimension self-orthogonal finite-length sequence [4][5]. Then two-dimension self-orthogonal finite-length sequence will be introduced. This sequence has good aperiodic correlation and a lot of varieties. A finite-length sequence $\{a_{M,l,i};\, i = 0,1,\cdots,M-1\}$ has length M and distinct number l, whose autocorrelation function is given by

$$\rho_{M,l,l,i'} = \frac{1}{M}\sum_{i=0}^{M-1} a_{M,l,i}a_{M,l,i-i'} = \begin{cases} 1 & ;i' = 0 \\ \varepsilon_{M-1} & ;i' = \pm(M-1) \\ 0 & ;i' \neq 0,\pm(M-1). \end{cases} \qquad (1)$$

The sequence is finite and aperiodic as $a_{M,l,i} = 0$ for i<0 and i>M-1, whereas its autocorrelation function is also finite and aperiodic. The shift-end value ε_{M-1} at left and right takes the smaller magnitude for the larger length M. The shifted sequences $\{a_{M,l,i-n};\, n = 0,1,\cdots,M-2\}$ satisfy the following orthogonality,

$$\frac{1}{M}\sum_{i=0}^{M-1} a_{M,l,i}a_{M,l,i-n} = 0,\ \ n = 0,1,\cdots,M-2. \qquad (2)$$

Fig.3 shows the aperiodic autocorrelation function of sequence $\{a_{M,l,i};\, i = 0,1,\cdots,M-1\}$, whose length is M=32, and the shift-end value $\varepsilon_{M-1} = 0.1$.

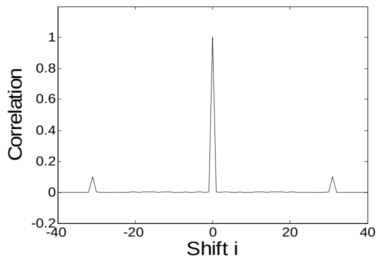


Fig.3 The aperiodic autocorrelation function.

A two-dimension self-orthogonal finite length sequence $\{a_{M_1,M_2,L,i,j}\}$ can be produced with one-dimension self-orthogonal finite-length sequences $\{b_{M_1,l_1,i};\, i = 0,1,\cdots,M_1-1\}$ and $\{b_{M_2,l_2,j};\, j = 0,1,\cdots,M_2-1\}$, whose sequence lengths are M_1 and M_2, sequence numbers are l_1 and l_2, ordinals are i and j, and shift-end values are ε_{M_1-1} and ε_{M_2-1}, respectively. The sequence $\{a_{M_1,M_2,L,i,j}\}$ and its aperiodic autocorrelation function are given by

$$a_{M_1,M_2,L,i,j} = b_{M_1,l_1,i} b_{M_2,l_2,j} \tag{3}$$

$$\rho_{M_1,M_2,L,L,i',j'} = \frac{1}{M_1 M_2} \sum_{i=0}^{M_1-1} \sum_{j=0}^{M_2-1} a_{M_1,M_2,L,i,j} a_{M_1,M_2,L,i-i',j-j'} = \begin{cases} 1 & ; i'=j'=0 \\ \varepsilon_{M_1-1} & ; i'=\pm(M_1-1), j'=0 \\ \varepsilon_{M_2-1} & ; i'=0, j'=\pm(M_2-1) \\ \varepsilon_{M_1-1}\varepsilon_{M_2-1} & ; i'=\pm(M_1-1), j'=\pm(M_2-1) \\ 0 & ; otherwise. \end{cases} \tag{4}$$

Fig.4 shows the aperiodic autocorrelation function of two-dimension self-orthogonal finite length sequence with $M_1=M_2=32$, and the shift-end value $\varepsilon_{M_1-1} = \varepsilon_{M_2-1} = 0.1$.

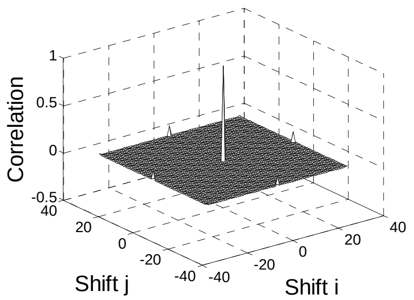


Fig.4 The aperiodic autocorrelation function of sequence $\{a_{M_1,M_2,L,i,j}\}$.

2.3 Embedding and Detection

In this paper, we use additive embedding rule:

$$F_{i,j} = G_{i,j} + w a_{L,i-i_0,j-j_0} \quad i,j = 0,1,\cdots N-1 \tag{5}$$

where $G_{i,j}$ is subband image LH_2 or HL_2, and $a_{L,i-i_0,j-j_0}$ is the shifted sequence as

$$a_{L,i-i_0,j-j_0} = a_{M_1,M_2,L,i-i_0,j-j_0}\ , \tag{6}$$

w is weight value, and $F_{i,j}$ is the watermarked sub-image.

In the detection process, a correlation function between the received sub-image $F'_{i,j}$ and the sequence $a_{L,i,j}$ is calculated as follows:

$$R_{F',a,i',j'} = \frac{1}{N \cdot N} \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} F'_{i,j} a_{L,i-i',j-j'} \tag{7}$$

where the peak value is normalized to 1, and the decision is

$$\begin{aligned} R_{F',a,i',j'} < T &\Rightarrow \text{ watermark is not present} \\ R_{F',a,i',j'} \geq T &\Rightarrow \text{ watermark is present} \end{aligned} \tag{8}$$

where T is a threshold. The threshold is

$$T = \frac{\varphi + \rho}{2} \tag{9}$$

where φ is the peak value of the cross-correlations between the desired and undesired sequences, and ρ is the autocorrelation peak value of the sequence. Because ρ is always 1, the threshold T is

$$T = \frac{\varphi + 1}{2}\,. \tag{10}$$

In this method, the information of the watermarking depends on the shifts i_0, j_0 and the distinct sequences of the sequence set. We can use two different sequences and positions or the same sequence and position to embed into subbands LH_2 and HL_2, respectively. If we use independently two sequences and positions in subbands LH_2 and HL_2, the outputs of decision 1 and decision 2 is given by d1 and d2, respectively. If we use the same sequence and position, the output of decision 0 is given by d0 which is the logistic OR of d1 and d2. Then the system is stronger against attacks.

3. Simulation Results

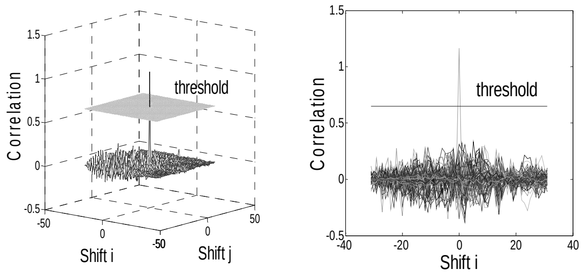
We test our scheme on the lena image with the size 256×256 and the intensity levels of 8 bits and thus N=64 in Eq.(5). In our experiment we use the two-dimension self-orthogonal finite length sequences $\{a_{M_1,M_2,L,i-i_0,j-j_0}\}$ with $M_1=M_2=32$, $\varepsilon_{M_1-1} = \varepsilon_{M_2-1}$ =-0.1, $0 \le i_0 \le 9$, $0 \le j_0 \le 9$ and the distinct numbers 25, and we fix w as a constant and choose w=5 to ensure a PSNR. The threshold of correlation detection is set up to T=0.65 from the cross-correlation peak $\varphi = 0.3$.

As shown in Fig.5, the PSNR between the original image and the watermarked image is 49.1dB, the watermark is perceptually invisible and the image with watermark appears visually identical to the original image. Fig.6 shows the correlation detector response in different visual angles. The noise derived from the original image is suppressed to low levels under the threshold T=0.65.

In order to evaluate the robustness of our scheme against unintentional and intentional attacks, we test the watermarked image with JPEG compression, additive noise, and filtering attacks.

(a) (b)

Fig.5 (a) Original image. (b) Watermarked image(PSNR=49.1dB).



(a) (b)

Fig.6 Correlation detection response in different visual angles. (a) Three-dimension representation. (b) Two-dimension representation.

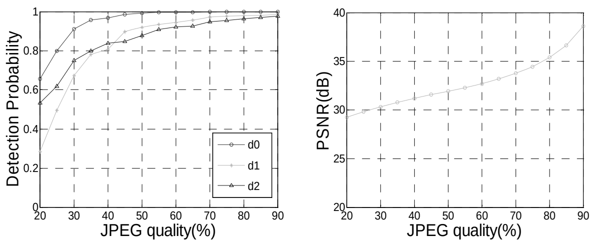
3.1 JPEG Compression

JPEG is a widely used compression format and the watermark should be resistant to this distortion.

In this experiment, we use detection probability (DP). In order to obtain the detection probability, we use 25 combinations of different sequences and embedded them into 100 different positions for one image quality factor. The image quality factor is varied from 20% to 90%, and we compute the detection probability for the quality factor of every 5% variation. The detection probability (DP) of correlator is defined by

$$DP = \frac{\textit{times of successful}\ \text{detection}}{2500} \times 100\,. \quad (11)$$

As shown in Fig.7, with the decreasing of the quality of the JPEG compressed image, the detection probability of correlator and PSNR also decreases, where d1, d2 and d0 are based on the outputs from Decision 1, Decision 2 and their logistic OR(Decision 0) in Fig.2(b). We can see that if we detect either watermark the detection probability of correlator is above 65% even when quality factor is as low as 20%, although the image is severely distorted.



(a) (b)

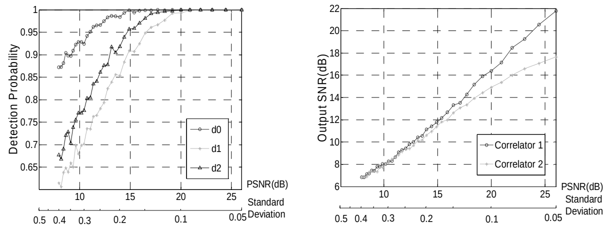
Fig.7 Results of JPEG compression with different quality factor. (a) Detection probability. (b) PSNR.

3.2 Adding Noise

Noise appears commonly in image processing and transmission. In this experiment, we add white Gaussian noise and salt and pepper noise into the watermarked image. The simulation results are shown in Figs.8 and 9, where the detection probability is computed at every 1000 different random noises.

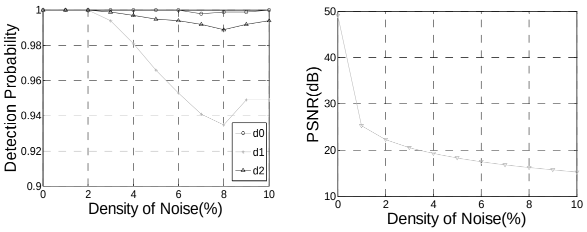
For the white Gaussian noise, the standard deviation is varied from 5% to 40% of the peak intensity 255, Fig.8(a) is the detection probability, and Fig.8(b) is the ratio of watermarked signal to noise in the detection. For the salt and pepper noise, the density of noise to bring the intensity to 255 or 0 is varied from 1% to 10% of the pixels 256×256.

Fig.9(a) is the detection probability, and Fig.9(b) is the PSNR.



(a) (b)

Fig.8 Results of white Gaussian noise attacks.
(a) Detection Probability. (b) Output SNR.



(a) (b)

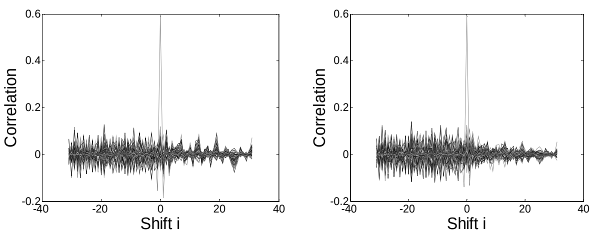
Fig.9 Result of salt and pepper noise attacks.
(a) Detection probability. (b) PSNR.

3.3 Filtering

Filtering is one of the common image processing. The watermarked image is filtered with 3×3 linear mean filtering and 3×3 median filtering. The result is shown in Table 1 and Fig.10. For this result, the correlation peak value is below the threshold, but the correlation peak is outstanding. If we select such threshold as 0.4, we can detect the watermark.

Table 1 Filter effect.

	PSNR(dB)	Correlation Peak value
3×3 linear mean filtering	27.76	0.60
3×3 median filtering	30.03	0.59



(a) (b)

Fig.10 Correlation peak of filtering. (a) Linear mean filtering. (b) Median filtering.

4. Conclusion

In this article, a novel image watermarking scheme in wavelet transform domain has been proposed. Because of using the self-orthogonal finite length sequences as the watermarks, the watermark detection does not need the original image. The experiment results demonstrate that the proposed method is highly robust to JPEG compression, additive noise and filtering attacks.

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