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An Adaptive All-odd Transformation Watermark Scheme

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Abstract

Combining discrete wavelet transform, human visual system, chaotic map and odd-even quantization, a novel watermarking scheme for 2D images is proposed in this paper. Encrypted watermarking and identity information are imperceptibly embedded in 2D images according to this scheme. For improving the accuracy of just noticeable distortion and enhance robustness of algorithm, the model adaptively adjusts the threshold intensity by adding weighting factor and strengthening the brightness sensitivity calculation method of just noticeable distortion. The bijection relationship is constructed between the image coefficients and watermarking bits by the way of all-odd transformation to the just noticeable distortion, so the scheme realizes blind extraction of watermark. The experimental results and analysis show that the proposed scheme can resist intentional or unintentional variety of attacks and have superiority comparing with existing schemes.

Keywords: *digital watermarking, just noticeable distortion, logistic mapping, zigzag scanning*

1. Introduction

Digital watermarking is a communication problem with side information, namely a watermarking system which completely boycott the interference between host signal and hide signal [1]. For getting a better visual effect, lots of work have been devoted to studying the HVS (human visual model). Zhou [2] etc. established a MJND model(just noticeable distortion in Multiview) for the study of HVS to stereoscopic masking effect. Literature [3-6] presented some algorithms which based on the DCT (Discrete Cosine Transform) compressible Watson model. Afterwards, the Barni perceptual model [7-11] based on DWT (Discrete Wavelet Transform) has been widely used in digital watermarking.

Fang [10] and Huang [11] etc. had improved on Barni model. They used the Barni model to determine the embedding strength. Fang chose a strong robustness cofficient through the analysis of the watermarking capacity as the embedding bit,thereby the imperceptivity of the watermark was improved. Huang described the probability density function of wavelet coefficients by using the Generalized Gaussian Distribution (GGD) to balance the imperceptivity and robustness. Because embedding location and cover image are needed in the watermark extraction, theirs algorithms have high complexity and can't achieve the blind extraction of watermark.

In order to overcome the above shortcomings, an adaptive all-odd transformation watermarking scheme is proposed. On the basis of the Barni model, using the luminance factor and weight factor to optimize the JND for improving the security of the watermark.Moreover,a blind extraction of watermark algorithm based on JND is proposed. The scheme not only has better imperceptivity and robustness, but also is convenient and highly efficient.

The rest of the paper is organized as follows. The proposed watermarking scheme, optimizing threshold, analyzing the all-odd transformation, the watermark embedding and extract-ion are detailed in Section 2. Experimental results and performance analyses are discussed in Section 3, and the conclusion is drawn in Section 4.

2. Proposed Watermarking Scheme

2.1. Model Overview

Figure 1 shows the proposed model of watermarking scheme.

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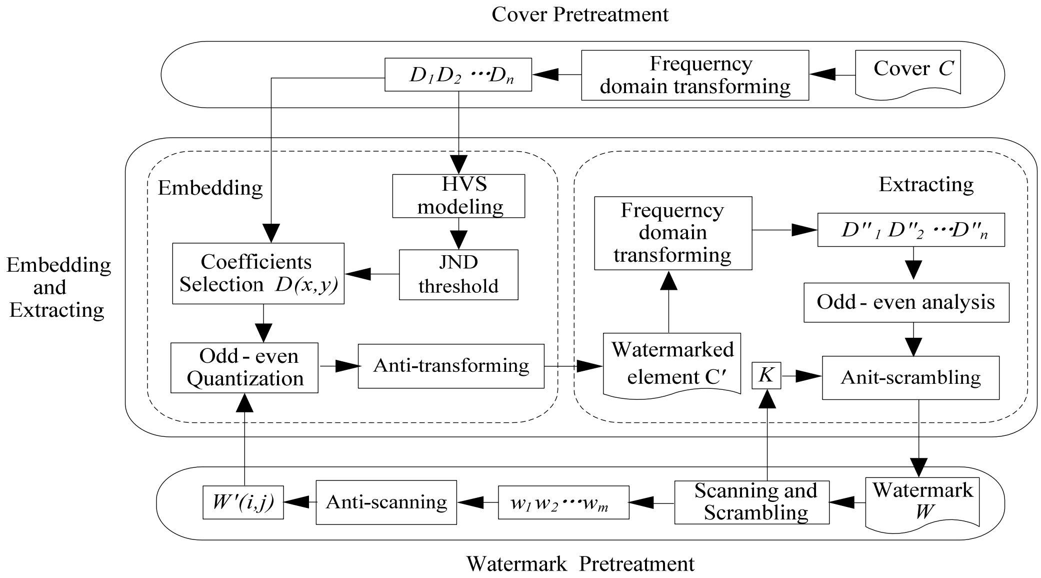

Figure 1. Model of Watermarking Scheme

The model of watermarking scheme consists of three modules described as follows:

(1) Cover pretreatment: Any cover is processed by frequency-domain transform and matrix of frequency coefficient is acquired.

(2) Watermark pretreatment: In the process,watermark is scanned and scrambled to get the final embedded sequence.

(3) Embedding and extracting watermark: As the intermediate portion of Figure1. When watermark is embedded, the cover frequency-domain coefficients after pretreatment are firstly processed by HVS model and the JND is acquired. The JND determines embedded strength. The encrypted watermark is embedded into frequency-domain coefficients using odd-even analysis, and the watermarked element are generated finally. The watermark can be extracted through frequency-domain transforming, odd-even analyzing and anti-scrambling of the water-marked element.

Model framework is described as an eight-element array: $F=f(C,W, C', W', EN, K, EM, EX)$. The detailed descriptions are as follows:

The set of cover is defined as $C=\{C_1、C_2…C_r…\}$. $D_1、D_2…D_n$ are the frequency-domain coefficients corresponding to the cover C_r.

$W=\{W_1、W_2…W_l…\}$, the set of watermark.

$C'=\{C'_1、C'_2…C'_r…\}$, the set of watermarked elements. $D'_1、D'_2…D'_n$ are the frequency-domain coefficients corresponding to the watermarked C'_r.

$W'=\{W'_1、W'_2…W'_l…\}$,the set of watermark processed by encryption which can be embedded in cover.

EN represents watermarking encryption algorithm. Watermark W_l is scanned and scrambled before embedded into the cover,so that the security of the watermark is enhanced. Variable *K* needed in watermark extraction is the key generated at the time of the watermark scrambling. The corresponding function is $(W',K)=EN(W)$.

EM represents watermarking embedding algorithm. The function is $C'=EM(C, W')$.

EX is the watermark extracting algorithm which is used to extract watermark from watermarked elements to prove the product copyright,etc. The function is $W=EX(C',K)$.

2.2. Model Analysis
2.2.1. JND Parameters Optimization

JND refers to the minimum distortion that can be identified in the experiment, which reflect the perception characteristics of HVS directly [5]. Therefore, shown from the model overview, the acquisition and processing of JND is the key part of the algorithm.

Barni's [8] definition about JND mainly considered the frequency sensitivity *F*(*l*,*θ*), luminance sensitivity *L*(*l*,*x*,*y*), textured and edge characteristics *T*(*l*,*x*,*y*). The value is the weighted result of three terms above and the basic equations are as follows:

$$JND_l^\theta(x,y)=\frac{1}{2}\cdot F(l,\theta)\cdot L(l,x,y)\cdot T(l,x,y)^{0.2} \quad (1)$$

$$F(l,\theta)=\begin{cases}\sqrt{2}, & if \quad \theta=1\\ 1 & ,otherwise\end{cases}\cdot\begin{cases}1.00, if\ l=0\\ 0.32, if\ l=1\\ 0.16, if\ l=2\\ 0.10, if\ l=3\end{cases} \quad (2)$$

$$L(l,x,y)=\begin{cases}2-A, & if \quad A<0.5\\ 1+A, & otherwise\end{cases}, A=\frac{1}{256}\cdot D_3^3\left(1+\left\lfloor\frac{x}{2^{3-l}}\right\rfloor, 1+\left\lfloor\frac{y}{2^{3-l}}\right\rfloor\right) \quad (3)$$

$$T(l,x,y)=\sum_{k=0}^{3-l}\frac{1}{16^k}\sum_{\theta=0}^{2}\sum_{i=0}^{1}\sum_{j=0}^{1}[D_{k+l}^\theta(i+\frac{x}{2^k}, j+\frac{y}{2^k})]^2 \cdot Var\left\{D_3^3\left(1+i+\frac{x}{2^{3-l}}, 1+j+\frac{y}{2^{3-l}}\right)\right\}_{i,j=0,1} \quad (4)$$

Where *l* is the sub-band at decomposition level, *θ*∈(0,1,2,3) represents high frequency, horizontal,vertical and low frequency component after transforming, $D^\theta_l(x,y)$ is the corresponding coefficient of coordinate (*x*,*y*).

Shown in Equation (1)-(4), the JND which corresponds to coefficient at the same place is same in every level of the sub-bands. In order to eliminate the problem, combine with HVS preferably and enhance the algorithm's robustness, this paper makes improvement as follows:

(1) Changing the luminance factor

For reducing the complexity of the algorithm, the DWT coefficients is normalized. Equation (3) is improved as follows:

$$L(l,x,y)=\begin{cases}2-A, & if A<\overline{A}\\ 1.5+A, & otherwise\end{cases} \quad (5)$$

$\bar{A}$ is the mean of *A*. Equation (5) can be better capture the eye brightness sensitivity because it can obtain the best matching with different covers that $\bar{A}$ is chosen.

(2) Adding a weighting factor

As the coefficients corresponding to different positions are different, the weighting factor is defined by its own attribute:

$$\alpha=\frac{D_l^\theta(x,y)}{\left|\overline{D_l^\theta(x,y)}\right|}, \ \overline{D_l^\theta(x,y)}$$ is the mean of each sub-band coefficient.

The value of thresholds can be adaptively changed by adding a weighting factor so as to adjust the embedding strength.

From all of above, Equation (1) is redefined as:

$$JND_l^\theta(x,y)=\frac{\alpha}{2}\cdot F(l,\theta)\cdot L(l,x,y)\cdot T(l,x,y)^{0.2} \quad (6)$$

2.2.2. All-odd Transformation

"All-odd transformation" is an adjustment to JND for making the threshold into "odd", which aims to construct a bijection relationship between the image coefficients and watermarking bits, realizes blind extraction of watermark. The equation is as follows:

If $round\ (JND_l^{\theta}(x,y)\times 10)$ is even, then

$$Q_l^{\theta}(x,y)=(round\ (JND_l^{\theta}(x,y)\times 10)+1)/10 \tag{7}$$

$Q^{\theta}_l(x,y)$ is the corresponding threshold of coordinate (x,y). For embedding the watermark by the odd-even modulation method, we let:

$$D_l'^{\theta}=\begin{cases} U_l^{\theta}\cdot Q_l^{\theta} & U_l^{\theta}\in even\ \ and\ \ w'=0 \\ \quad or & U_l^{\theta}\in odd\ \ and\ \ w'=1 \\ (U_l^{\theta}-1)\cdot Q_l^{\theta} & U_l^{\theta}\in odd\ \ and\ \ w'=0 \\ (U_l^{\theta}+1)\cdot Q_l^{\theta} & U_l^{\theta}\in even\ \ and\ \ w'=1 \end{cases}\ ,U_l^{\theta}=round\ [\frac{D_l^{\theta}(x,y)}{Q_l^{\theta}(x,y)}] \tag{8}$$

Wherein, *D'* represent the watermarked coefficient and *w'* is the watermarking bit. Since there is only the watermarked information when watermark detection, through reverse deduction, the principle of watermark blind extraction is as follows:

If U^{θ}_l=2N, $D'^{\theta}_l= U^{\theta}_l\cdot Q^{\theta}_l$=2N, then w'=0,
or $D'^{\theta}_l=(U^{\theta}_l+1)\cdot Q^{\theta}_l$=2N+1, then w'=1.
If U^{θ}_l=2N+1, $D^{\theta}_l{}'= U^{\theta}_l\cdot Q^{\theta}_l$=2N+1, then w'=1,
or $D'^{\theta}_l=(U^{\theta}_l-1)\cdot Q^{\theta}_l$=2N, then w'=0.

Thus the watermarking information can be directly obtained by the parity of watermarked image coefficients.

2.3. Watermark Embedding and Extraction

For some DWT coefficients of the intermediate and high frequency sub-bands are 0 or negative, DWT coefficients may be overflow when watermark is embedded. For above reason, the 4-th level low-frequency sub-band is selected to be embedded watermark. The basic steps are:

Step 1. Watermark pretreatment: Binary image is scanned using Zigzag method and reduced dimension. The scanned results W_i, $i\in(1,2\ldots m)$ are scrambled by the Logistic map (x_0=0.2589), Setting key $K=x_0$. Finally, watermarking $W'(i,j)$, $i\times j\in(1,2\ldots m)$ can be obtained from W_i by the Zigzag anti-scanning.

Step 2. Calculation of JND and threshold: Cover image is decomposed to four levels to get the coefficients $D^{\theta}_l(x,y)$.Compute the $JND^3_3(x,y)$ and $Q(x,y)$, $x\in(1,2\ldots M/16)$, $y\in(1,2\ldots N/16)$ through the equations in Section2 respectively.

Step 3. Embedding watermark: The coefficient of current embedded location is modulated through the Equation(8).

Step 4. Generating the watermarked image: The image with embedded watermark will be generated after IDWT.

Step 5. Watermark extraction and decryption:Based on the Step 2, watermark extraction is quick and easy, which is making a judgment for parity of coefficients after DWT. Extraction equation is:

$$w_i''=\begin{cases} 0 & D''\ is\ \ even \\ 1 & D''\ is\ \ odd \end{cases} \tag{9}$$

The results are processed by decryption of chaotic sequence using the key K, and obtained the watermark information.

3. The Experimental Results and Analysis

3.1. Evaluation Criterion and Basic Experiment Simulation

The peak signal-to-noise ratio (PSNR) and structural similarity(SSIM) are the evaluation of qualities of watermarked image. Normalized correlation (NC) and bit error ratio (BER) are used as the extract watermark performance index, T represents the elapsed time.

$$PSNR = 10\lg[\frac{M \times N \times 255^2}{\sum_{x=1}^{M}\sum_{y=1}^{N}[D(x,y) - D'(x,y)]^2}] \tag{10}$$

$$SSIM(D, D') = [l(D, D')]^{\alpha} \cdot [c(D, D')]^{\beta} \cdot [s(D, D')]^{\gamma} \tag{11}$$

$$NC = \frac{\sum_{i,j} w(i,j) \cdot w''(i,j)}{\sqrt{\sum_{i,j} w(i,j)^2}\sqrt{\sum_{i,j} w''(i,j)^2}} \tag{12}$$

$$BER(w, w'') = \frac{100}{mn}\sum_{i,j}\begin{cases}1, & w \neq w'' \\ 0, & w = w''\end{cases} \tag{13}$$

In Equation (11), *α*, *β* and *γ* are represent the weight parameters, SSIM respectively comparing from three aspects: the comparison in luminance (*l* (x, y)), in contrast (*c* (x, y)) and in structure (*s* (x, y)).

Taking the 512×512 standard gray-level Lena as testing image and 32×32 binary image as watermark, Figure 2 are the simulation results:

(a) Original image (b) Watermark (c) Watermarked image (d) Extract watermark

Figure 2. Embedding and Extracting Watermark

Shown in Figure 2(a) and (c), the watermarked image has no difference with the original image, therefore it has the characteristic of good imperceptivity. At the same time, there is no distortion in extract watermark in Figure 2(d). In experiment, the parameters are set to that BER=0, NC=1.

To reflect the performance of improved threshold module, this original method will be compared with proposed method. Method A is the method in reference [8]. Method B is the algorithm that it is the same as method A but watermark is embedded in the low frequency sub-band at the forth level. Method C is the proposed method. In method D, luminance is changed while variables are not added. A variable is added but the luminance is unchanged in method E. Comparison results are shown in Table 1.

Table 1. Experimental Results of Method Comparing

method	method A	method B	method C	method D	method E
PSNR	35.90	40.15	48,75	48.42	47.22
SSIM	0.988	0.999	0.999	0.999	0.999
T	3.5694	0.3475	0.2927	0.3193	0.3477

In Table 1, PSNR and SSIM are both changed whenever the model is changed or not. Comparing method A with method B, it is obvious that when watermark embedded in the low frequency the quality of images is better than in the intermediate or high frequency. Comparing methods C, D and E, changing luminance or variables of model can increase subjective quality, but they are slightly less than both changing. For the complicated calculation in equation (3) of original method, the time is far more than that of the reference model.

3.2. Comparison of Algorithms

For reflecting the universality of algorithm, watermark is embedded in five different types of images. Table 2 compared algorithm with reference [8] and reference [10].

Table 2. Experimental Results of Different Images

The tested image		Fang's method [10]	Barni's method [8]	Barni's method and embedding in LL3	Proposed method
PSNR	milkdrop	40.23	34.49	40.18	42.58
	man	36.23	30.85	38.10	43.32
	couple	36.23	33.62	38.82	44.42
	plane	36.98	33.69	37.99	44.42
	lake	33.85	31.57	36.76	42.58
SSIM	milkdrop	0.988	0.994	0.999	0.999
	man	0.994	0.996	0.999	0.999
	couple	0.994	0.995	0.999	0.999
	plane	0.996	0.992	0.998	0.999
	lake	0.992	0.993	0.998	0.999

In Table 2, five kinds evaluation of image quality applied on the proposed method are superior to the others. Therefore, Table 2 confirmed the feasibility of proposed method.

For describing the robustness of the proposed algorithm, Method 1 is the method in reference [10], method 2 is the Huang' s method [11]. Method 1 and method 2 are compared with the proposed algorithm which represents the method 3 in this paper. Cropping, adding noise, filtering, scaling and rotation in three kinds of methods respectively, the experimental results are shown in Table 3.

Table 3. Simple Attack

Attack		Cropping		Scaling		Adding noise		Filtering		Rotation	
		1/8	1/2	25%	200%	Gaussian 0.005	Speckle 0.05	Median 5×5	Low and pass	5°	30°
PSNR	1	15.37	8.46	29.85	38.77	22.92	18.25	32.86	38.54	19.42	13.58
	2	15.49	8.46	29.98	42.97	22.99	18.30	32.17	41.84	15.24	13.59
	3	18.19	8.47	29.87	42.68	32.69	33.62	33.99	40.73	19.45	13.60
SSIM	1	0.851	0.499	0.667	0.952	0.523	0.520	0.701	0.957	0.938	0.783
	2	0.874	0.499	0.670	0.955	0.515	0.521	0.705	0.955	0.349	0.782
	3	0.875	0.501	0.669	0.956	0.673	0.735	0.703	0.960	0.942	0.788
BER	1	0.03	0.28	0.15	0	0.02	0.06	0.09	0.01	0.01	0.07
	2	0.05	0.28	0.35	0.08	0.23	0.31	0.27	0.09	0.05	0.16
	3	0.04	0.24	0.08	0	0.06	0.02	0.17	0	0.001	0.06
NC	1	0.977	0.810	0.901	1	0.512	0.960	0.940	0.999	0.992	0.957
	2	0.954	0.811	0.772	0.949	0.855	0.801	0.821	0.938	0.967	0.904
	3	0.967	0.864	0.952	1	0.670	0.986	0.900	1	0.993	0.956

From the PSNR and SSIM shown in Table 3, method 2 still have higher numerical value after the watermarked attacked in which showed good imperceptivity.However,it can be seen from the BER and NC that the extracted watermark of method 2 is worst. Comparing method 1 and method 3 in the four sets of data, the former attacked watermarked images and analysis of watermark extracted are both slightly worse than the latter. Thus, proposed method resists these five kinds of attacks in a certain scope.

The JPEG compression is implemented to the watermarked images, and the experimental results are presented in Figure 3.

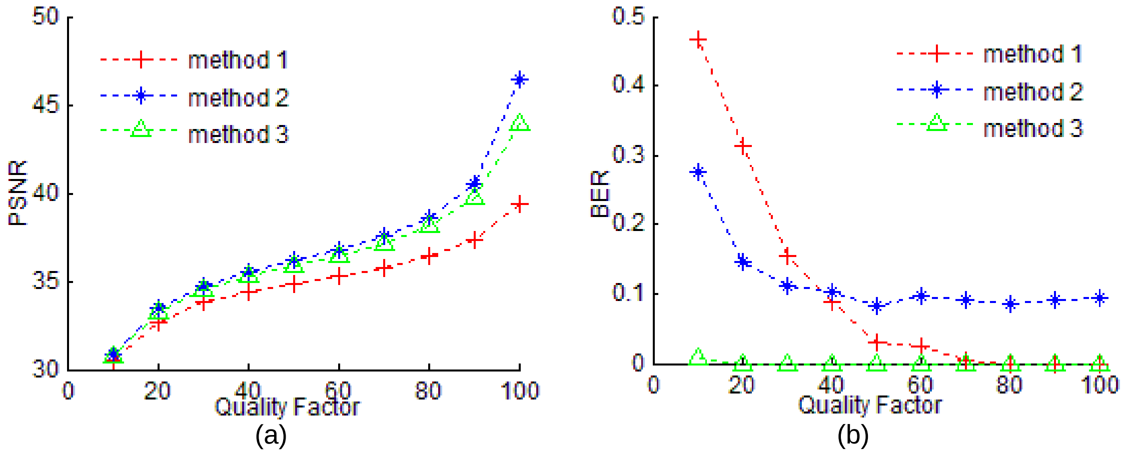

Figure 3. JPEG Compression

In the Figure 3(a), it is obvious that PSNR of three methods increase with the increasing of the quality factor (QF). PSNR of method 3 is bigger than that of method 1 but smaller than method 2. Therefore, imperceptivity of watermarked images is the best in method 2. From the Figure 3(b), robustness of method 3 is the strongest and extracted watermark is light distortion when QF=10. However, it is distortion when QF=100 and completely distorted when QF=20 in method 2.

From the analysis of the watermarking model, proposed model greatly enhance the robustness and imperceptivity of watermarking scheme, the value of performance evaluation is better than other methods, and algorithm model has been improved greatly.

4. Conclusion

Analyzing the feature of the watermarking scheme in this paper, the new watermarking model, which improves threshold calculation method based on the odd-even quantization, is proposed on the basis of the Barni's model. The model ensures imperceptivity of the watermark by calculating the JND and regulating threshold with improved method, and enhances the robustness with the help of scrambling and odd-even quantization of the watermark. Moreover, blind extraction of watermark can be realized by using all-odd transformation. Comparing with the existing algorithms, the proposed model has made great progress in the ability of resisting geometric attacks. This model is not confined to cover, the selection of watermark embedded is also not aimed to the gray image or a binary image, color images, text files, video, audio, etc. can also act the both. The application of the watermarking scheme will be a good extension.

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