Digital Image Watermarking Based on Texture Block and Edge Detection in the Discrete Wavelet Domain

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***Abstract*—A new digital image watermarking algorithm based on texture block and edge detection in the discrete wavelet domain is proposed in order to balance between the invisibility and robustness and improve the ability of resisting to geometric attacks of the digital image watermark. In the algorithm, the texture blocks are extracted after the edge detection for the original image with the canny operator by using the masking property of human visual system, in which the watermark is embedded adaptively both in the low-frequency sub-band and the high-frequency sub-band in the discrete wavelet domain. The experiment result shows the watermark has good invisibility and robustness as well as the ability of resisting to geometric attacks by using the algorithm proposed in this paper. At the same time, three keys generated in the embedding process that can raise the security of the watermark.**

Keywords-digital image watermarking; texture block; edge detection; discrete wavelet transform

I. INTRODUCTION

The information hiding is one of the most popular spots in the field of information security, whose driving forces are the two problems, i.e. copyright protection and status monitoring. The digital watermarking technology makes the specific information embedded into the digital media such as image, voice, video, and text files as the digital media protection, in order to achieve the purpose of identification, annotation and copyright protection.

General watermarking algorithms are resistant to compression, filtering, and other conventional attacks, but are often unable to cope with geometric attacks. Currently, there are two kinds of watermarking algorithm to resist to geometric attacks. The first kind of the two algorithms embed the watermark information in the pixel frequency domain or transform coefficients, which has weak capacity to resist to clipping and noise attacks simultaneously. The other watermarking algorithm is a localized digital watermarking scheme based on the image content and resistant to local geometric attacks such as clipping attack. The partial digital watermark is the method that embeds the watermark into a plurality of localized positions of the image. Celik et al [1] divided the kind of algorithm into three steps. The first step is the extraction of feature points. The second step is the image segmentation based on the feature points and regional calibration after image segmentation. The last one is embedding and extraction of the watermark. Kutter et al [2] considered that the extracted feature points generally should be not sensitive to the noise, covariant geometric transformation and local (the rest of the feature points cannot be changed after image clipping). Kim et al [3] indicated that the image edge met the properties of embedding the watermark because of its feature of the affine transformation invariance. Therefore, the image edge should be extracted so as to obtain the watermark that is resistant to geometric attacks and classified according to the strength. The invisibility and robustness of the watermark can be assured by using the texture masking property of HVS (Human Visual System) and the affine invariance of the image edge.

Digital watermarking based on DWT (Discrete Wavelet Transform) has obtained widespread concern because that it has excellent properties of multi-resolution representation and local time-frequency analysis and is easily compatible with the compression standard. Its basic idea for the image analysis is dividing the image into several sub-images in different space and different frequency by using the multi-resolution decomposition. Currently, there are two kinds of digital watermarking algorithms in the discrete wavelet domain. One is embedding the watermark into the lowest frequency sub-band [4], which makes the invisibility of the watermark reduced greatly because the low-frequency sub-land has the most information of the original image, although it can enhance the robustness to a certain extent. While the other one is embedding the watermark into the significant coefficients of the high-frequency sub-band namely the larger amplitude coefficients [5-6], which can make the robustness declined because the edge details in the high-frequency sub-band are vulnerable to external factors although it can improve the invisibility of the watermark to a certain degree.

A new digital image watermarking algorithm based on texture block and edge detection in the discrete wavelet domain is proposed in order to balance between the invisibility and the robustness and improve the ability of resisting to geometric attacks of the digital image watermark. For the purpose, embed the digital watermark into the high-frequency and low-frequency sub-brands in the discrete wavelet domain of texture blocks adaptively by using the masking property of human visual system.

II. KEY TECHNOLOGIES

A. Human Visual System

For a long time, a variety of visual masking effects were discovered by observing the visual phenomenon of human eyes and combining the research of visual physiology, psychology and other aspects. If the visual masking effects of human eyes are utilized fully in the process of embedding watermark, the invisibility and robustness will be improved greatly. A plenty of researches showed the following properties:

- Human eyes have different sensitivities to different gray scales which to be the strongest to the medium gray scale. Besides, the sensitivity declines both in the directions of the low and high gray scale non-linearly.
- Human eyes are far more sensitive to the noise on the smoothing zone of the image than the texture area.
- As the image edge information is important to human eyes and vulnerable to factors extraneous noise or other conventional image processing, the edge quality should be ensured to avoid the large damage.

We can lean from the above that HVS provides an important theoretical basis, i.e. the digital watermark should be embedded into the texture or edge part of image instead of the smooth part in order to ensure the invisibility [7-8].

B. Discrete Wavelet Transform

A two-dimensional discrete wavelet transform (DWT) of the signal X can be regarded as a hierarchical four-channel filter operation. Transform coefficients in the three high-frequency sub-bands LH1, HL1, HH1 and the only one low-frequency sub-band LL1 can be obtained by using high-pass and low-pass filters to the rows and columns respectively, and then continue to decompose the sub-band LL1 until achieve the required number of stages. The low-frequency sub-band represents the best approximation of the original image under the condition of the largest scale and the minimum resolution decided by DWT decomposition level. Its statistical characteristics are similar to the original image, and most of the energy of the image is concentrated in it. While the high-frequency sub-bands represent the details of the original image in different scales and resolutions. The lower the resolution is, the higher the proportion of useful information is. Namely, the image is divided into several stages after DWT, as a result, the low-frequency sub-image LL_j is most important, followed by HL_j and LH_j, and the high-frequency sub-image HH_j is the least important relatively for the same level of image. For the different level, the higher level is far more important than the lower one. Hence, the ranking of sub-bands of the wavelet image according to the strength of the importance is LL_k, HL_k, LH_k, HH_k, HL_{k-1}, LH_{k-1}, HH_{k-1}, $\cdots$, HL_1, LH_1, HH_1.

C. Digital Image Watermarking Based on Edge Detection

The edge of the image is one of the basic characteristics of the image. The so-called edge is the pixel set of whose surrounding pixel gray has step or roof changes. The image edge can be detected by investigating the gray variation in some neighborhood of each pixel and taking advantage of directional derivative variation of first or second order directional derivative of the adjacent edge. The edge detection operator checks the neighborhood of each pixel and quantizes the gradation variation rate including the determination of the direction. The commonly used methods of edge detection are: canny operator [9], second derivative zero crossing algorithm, gradient operator, Laplace operator, Sobel operator etc. Canny operator is a kind of edge detection operators with excellent performance and widely used in many fields of image processing. The basic idea of the canny operator is smoothing filtering on the image with a certain Gaussian filter firstly and processing for the image after smoothing filtering by using a so-called non-maxima suppression technology, and then the required image edge can be obtained.

The process of edge detection using canny operator is: convoluting on the image using Gaussian function firstly and then finding the zero-crossing point namely the edge points. The specific algorithm is as follows:

- Filtering on the image using Gaussian filter to remove the image noise.
- Calculate the magnitude of the gradient M and the direction Q. The following template of 2×2 can be used as a first-order approximation of the partial differential in the x-direction and y-direction.

  $$P=\frac{1}{2}\times\begin{pmatrix}-1 & 1\\ -1 & 1\end{pmatrix} \qquad Q=\frac{1}{2}\times\begin{pmatrix}1 & 1\\ -1 & -1\end{pmatrix}$$

  Therefore, the magnitude of the gradient M and the direction Q can be calculated.

  $$M(i,j)=\sqrt{P^2(i,j)+Q^2(i,j)}$$
  $$\theta(i,j)=\arctan\left[Q(i,j)/P(i,j)\right]$$

- Use the non-maxima suppression technology. The larger the value of the amplitude of the image array $M(i,j)$ is, the greater the gradient value of the corresponding image is. This is not enough to determine the edge, however, the roof with amplitude images should be refined so that a refinement edge can be generated.

We can learn from the above analysis that the watermark should be embedded into the texture blocks because human eyes are not so sensitive to the noise in the strong texture religion based on HVS. Besides, the watermark should be embedded into the high-frequency sub-bands and the low-frequency sub-bands respectively with different embedding strength because if embedding the whole watermark into only the high-frequency sub-bands, the robustness of the watermark will decline. In addition, it will be difficult to resist to geometric attacks such as clipping attacks if embedding the watermark into the whole image. Hence, the watermark should be embedded into a plurality of localized positions of the image using the edge detection method. Therefore, a new digital image watermarking algorithm based on texture block and edge detection in the discrete wavelet domain is proposed. In the algorithm, the texture blocks are extracted after the edge detection for the original image with the canny operator by setting a threshold. The watermark is embedded adaptively both in the low-frequency sub-band and the high-frequency sub-band in the discrete wavelet domain of the texture blocks.

III. DIGITAL WATERMARK EMBEDDING

Using the method of partitioning blocks to extract the local religions with good texture properties as well as improve the efficiency of the algorithm. In the algorithm, regard the number of edge points as the parameter for classification because the edge points are the characterization of the image gray mutation and the more edge points in the block are, the stronger the textures are.

Let the original image $I=\{x(i,j),1\le i\le M,1\le j\le N\}$, the binary watermark image $W=\{\omega(i,j),1\le i\le P,1\le j\le Q\}$, where i and j represent the pixel values of the i-th row and the j-th column of the original image and the watermark image respectively. The watermark embedding algorithm flowchart is showed in Fig.1. The steps of embedding the watermark are as follows:

A. Watermark Arnold Scrambling

Make the original watermark Arnold scrambling with the scrambling time K_1 and then the first key K_1 generates. The water image after scrambling is W^*.

B. Edge Detection

Edge detect for the original image I with the canny operator. The obtained binary image is B.

C. Partition Blocks

Partition the binary image B and the original image I into R blocks B_k and I_k ($k=1,2,\cdots,R$), and both of the size are $L\times L$. B_k and I_k are corresponding. Calculate the number of edge points s in B_k. Let the threshold be T. The texture blocks are extracted whose number of the edge points is more than T. Extract the original image blocks I_k corresponding to the texture blocks as the carrier of embedded watermark. The number of extracted blocks is U.

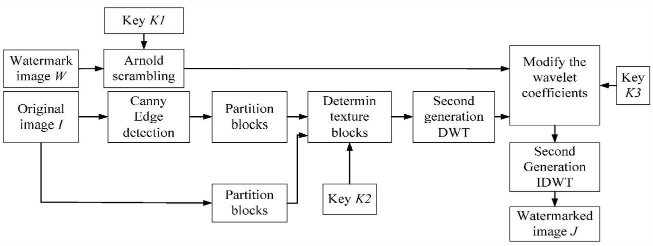


Figure 1. Digital watermark embedding algorithm flowchart

D. Second Generation Discrete Wavelet Transform

Second generation discrete wavelet transform for the texture blocks I_c ($c=1,2,\cdots,U$). Embed the watermark of different strength into the low-frequency sub-band LL1 and high-frequency sub-brands LH1, HL1 and HH1. The formula of embedding the watermark is (1).

$$I_c^*(i,j)=I_c(i,j)\times\left[1+\alpha\times W^*(h)\right]$$
$$c=1,2,\cdots,U;U=P\times Q/4$$
$$i=1,2\cdots,L/4;j=1,2\cdots,L/4;h=1,2\cdots P\times Q \quad (1)$$

where $I_c(i,j)$ is the coefficients of each sub-band after wavelet transform for the original texture blocks. α is the strength coefficient and $W^*(h)$ is the watermark component after scrambling. $I_c^*(i,j)$ is the wavelet coefficients of the modified texture blocks. The second key K_2 generates which can be used in extracting the watermark information, namely the position of the extracted texture block I_c.

E. Determination of the Intensity Fctor α

α is divided into two kinds α_1 and α_2 because the low-frequency sub-brand and the high-frequency sub-brand have different visual masking properties and the robustness after embedding the watermark is also different. Choose α_1 in the low-frequency and choose α_2 in the high-frequency sub-brand. Define α_1 and α_2 as (2) according to the literature [10]:

$$\alpha_1=0.009134\times\alpha_0\times\lg\left(|C-128|+10\right)$$
$$\alpha_2=\alpha_1\times\lg(D+10)\quad \alpha_0=\frac{\alpha}{2}=\frac{0.01\times A}{127} \quad (2)$$

where A is the pixel average of the original image, C is the average of the low-frequency blocks of the texture block I_c, and I_c is the average coefficient of the corresponding each high-frequency sub-images. Embed the watermark into different frequency brands adaptively with α_1 and α_2. The third key K_3 generates, namely the intensity factor of embedding the watermark.

F. Second Generation Inverse Discrete Wavelet Transform

The image J which has the scrambling watermark generates after second generation inverse discrete wavelet transform.

IV. EXTRACTION OF THE DIGITAL WATERMARK

The extraction and the embedding of the digital watermark are reciprocal process. The watermark extraction algorithm flowchart is showed in Fig.2.

The specific process for the digital watermark extraction is as following according to the watermark embedding algorithm.

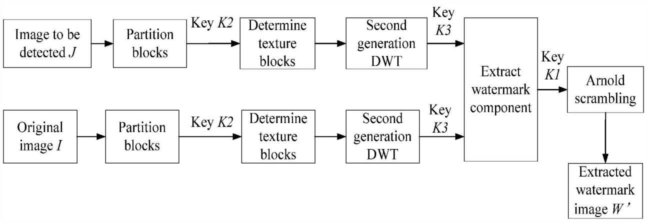


Figure 2. Digital watermark extracting algorithm flowchart

A. Partition Blocks

Partition the image to be detected J and the original image I into R blocks J_k and I_k ($k = 1, 2, \cdots, R$), and both of the size are 32×32 . J_k and I_k are corresponding in position.

B. Determination of Texture Blocks

Determine texture block set $U = \{U_k, k = 1, 2, \cdots, P \times Q / 4\}$ from the R blocks of the original image I according to the key K_2 generated in the process of embedding watermark. Extract the corresponding blocks from J as the texture block set to be measured $U^{'} = \{U^{'}_k, k = 1, 2, \cdots, P \times Q / 4\}$ according to the position of the texture blocks set.

C. Second Generation Discrete Wavelet Transform

Second generation discrete wavelet transform for the extracted $U^{'}_k$ and the corresponding U_k . Calculate the intensity factor α_1 and α_2 according to the method of embedding the watermark. Extract the watermark component according to (3) and (4).

$$W^*(h) = \left[U^{'}_k(i,j) / U_k(i,j) - 1\right] / \alpha \tag{3}$$

$$h = 1, 2, \cdots, P \times Q; i = 1, 2, \cdots, L/4; j = 1, 2, \cdots, L/4 \tag{4}$$

where $U^{'}_k(i,j)$ is the coefficients of each frequency brand of the texture blocks to be measured after second generation discrete wavelet decomposition. $U_k(i,j)$ is the coefficients of each frequency brand of the texture blocks of the original image after second generation discrete wavelet decomposition and is corresponding to $U^{'}_k(i,j)$. Judge the value of $W^*(h)$. If it is more than 0, the watermark component exists and let the value be 1. If not, let the value be 0.

D. Arnold Anti-scrambling

Make the extracted water component $W^*(h)$ Arnold anti-scrambling according to the key K_1 . And then the extracted watermark image $W^{'}\{\omega^{'}(i,j), 1 \le i \le P, 1 \le j \le Q\}$ can be obtained.

E. Evaluation of the Watermark

Determine the degree of similarity between the extracted water image and the original water image. It is the most effective to use the subjective approach for meaningful watermark. At the same time, the normalized correlation coefficient NC as (5) and the peak signal to noise ratio $PSNR$ as (6) are used in this paper to evaluate the degree of similarity between $W^{'}$ and W and the quality of the image embedded watermark.

$$NC = \frac{\sum\left[\omega^{'}(i,j)\omega(i,j)\right]}{\sum_{i,j}\omega^2(i,j)} \tag{5}$$

$$PSNR = 10\lg\frac{255^2}{\frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[I(i,j) - I^{'}(i,j)\right]^2} \tag{6}$$

where M and N are the size of the image, $\omega(i,j)$ and $\omega^{'}(i,j)$ are the pixel values of the original watermark image and the extracted watermark image respectively, and $I(i,j)$ and $I(i,j)$ are the pixel values of the original image and the watermarked image respectively.

V. SIMULATION RESULTS AND ANALYSIS

We used the Lena image of 256×256 and 256 gray scales as the original image and the binary text image of 32×32 as the original watermark to test the performance of the algorithm. The original image was divided into blocks of 8×8 . The effect of embedding watermark is showed in Fig.3 and Fig.4.

We can see that the watermarked image is so similar with the original image visually from Fig.3. The invisibility is ensured effectively. From Fig.4, we can see that the scrambling watermark has good confidentiality.

Test the ability of resisting to geometric attacks of the algorithm by image processing such as jpeg compression, noise, clipping, rotation, and median filter. The results are showed in Table 1, Table 2, Table 3, and Table 4.

(a) (b) (c)

Figure 3. (a) Original image. (b) Edge image. (c) Watermarked image

(a) (b) (c)

Figure 4. (a) Original watermark. (b) Scrabling watermark when K_1 =5. (c) Extracted watermark

The results show that the algorithm has good performances against the clipping attack. The watermark image can be still identified clearly in the condition of clipping the main part of the original image and the value of NC is close to 1. Compare with the extracted watermarks under different attacks and the value of NC and we can see that the robustness is the best under the jpeg compression attack. And the robustness is better under the condition of adding salt and pepper noise than Gaussian noise of the same coefficient. The robustness after image rotation is also good. The watermark after median filtering has the worst performance among the attacks which should be improved in the further study.

TABLE I. JPEG COMPRESSION OF DIFFERENT DEGREES

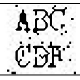
Attack	JPEG compression		
	Quality=95	*Quality=50*	*Quality=30*
Extracted watermark			
PSNR	37.2719	32.5313	29.2796
NC	1	0.9795	0.9533

TABLE II. ADDING DIFERENT NOISE

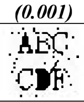
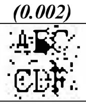
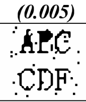
Attack	Adding noise			
	Gaussian (0.001)	*Gaussian (0.002)*	*Salt & Pepper (0.002)*	*Salt & Pepper (0.005)*
Extracted watermark				
PSNR	31.0209	27.9748	31.6226	28.7991
NC	0.9134	0.8805	0.9863	0.9601

TABLE III. CLIPPING ATTACK

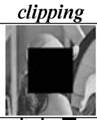
Attack	Clipping			
	Random clipping	*1/8 clipping*	*Quarter clipping*	*Center clipping*
Cropped image				
Extracted watermark				
PSNR	19.3698	21.0356	11.9469	11.5893
NC	0.8412	0.9282	0.8373	0.8179

TABLE IV. ROTATION AND MEDIAN FILTERING

Attack	Rotation and median filtering attacks		
	Rotate 5 degrees	*Rotate 10 degrees*	*3*3 Median filtering*
Attacked image			
Extracted watermark			
PSNR	23.3373	20.8347	29.7812
NC	0.9331	0.9100	0.8935

In short, the watermark using the algorithm proposed in this paper has good invisibility and robustness. It balances the two contradictory aspects and also improves the security of the watermark.

VI. CONCLUSION

In order to balance the invisibility and robustness and improve the ability of resisting to geometric attacks of the digital image watermark, a new digital image watermarking algorithm based on texture block and edge detection in the discrete wavelet domain is proposed. In the algorithm, the texture blocks are extracted after the edge detection for the original image with the canny operator by using the masking property of human visual system, in which the watermark is embedded adaptively both in the low-frequency sub-band and the high-frequency sub-band in the discrete wavelet domain. The results showed that the algorithm is effective to balance the invisibility and robustness of the digital watermark and improve the security. It also has good ability of resisting to geometric attacks. How to enhance the capacity of the embedded watermark and improve the robustness is the further study.

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