A blind watermarking algorithm based on DWT and SVD

XUAN Chun-qing[1], XUAN Zhi-wei[2], ZHANG Xia[2], CHEN Bao-li[2]

(*1. Zhengzhou Chenggong University of Finance and Economics, Department of Information Engineering, Gongyi 451200, China; 2. School of Instrument and Electronics, North University of China, Taiyuan 030051, China*)

Abstract: This paper presents a new digital image blind watermarking algorithm based on combination of discrete wavelet transform (DWT) and singular value decomposition (SVD). First of all, we make wavelet decomposition for the original image and divide the acquired low frequency sub-band into blocks. Then we make singular value decomposition for each block and embed the watermark information in the largest singular value by quantitative method. The watermark can be extracted without the original image. The experimental results show that the algorithm has a good imperceptibility and robustness.

Key words: discrete wavelet transform; singular value decomposition; a blind watermarking algorithm; robustness

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0 Introdution

With the rapid development and extensive applications of computer network, digital media illegal tampering, copying and piracy have become some growing problems in the computer age. The copyright protection of digital media is becoming an urgent problem which should be solved as soon as possible. As an important branch of the information security, digital watermarking technology provides a new way for copyright protection and security of multimedia information. Watermarking technology uses signal processing method to embed copyright information into multimedia and plays an important role in the copyright protection and secret communication[1].

The discrete wavelet transformation (DWT) has the character of good multi-resolution and is compatible with JPEG2000 and MPEC-4 compression standard. It can also be used to analyze the local time-frequency. Thus, the digital image watermarking algorithm based on DWT has gained widespread attention in recent years. However, the wavelet transformation cannot resist the attack of geometric invariance. When attacked by geometric, the embedded watermark in the image will be destroyed and the watermark will not be extracted from the image. Thus, the applications and development of the wavelet transformation in digital watermarking have been greatly limited[2]. Based on the mathematical theory, singular value decomposition (SVD) can resist geometric attack. Therefore, more and more attention has been paid on the watermarking technology based on SVD. This paper presents a blind watermarking algorithm method based on DWT and SVD. This algorithm can enhance the imperceptibility and robustness of the watermark by making full use of the characteristics of wavelet transformation of multi-resolution and the inherent characteristics of SVD. The watermark can be extracted without using the original image, but the wavelet decomposition levels, the embedding position and the SVD quantization strength factor are still needed. The new algorithm has excellent performance of imperceptibility, and can resist the attacks of JPEG compression, additive noise and cropping.

1 Watermarking algorithm

1.1 Discrete wavelet transformation

DWT is a kind of information analysis theory developed in recent years, which has the character of multi-resolution. The image is decomposed into three high frequency generations and a low-frequency offspring by DWT, where the low-frequency offspring can also be decomposed. The low-frequency band is the most approximate with the

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Corresponding author: XUAN Chun-qing (zhangxuanchunqing@163.com)

original image in wavelet domain, and most of the image energy is focused in this region. The embedded watermark is not easily to be attacked, but the invisibility is poor. The image's distribution details in different scales are focused in high frequency band. Invisibility of the embedded watermark in this region is good, but it is easily to be modified if it is attacked, and many details are lost in the compression process[3]. Three-level-wavelet decomposition can improve robustness of the image but the image is distoried obviously when the watermark is embedded. The wavelet decomposition meets the requirement of imperceptibility but the robustness is poor[4]. In order to obtain better robustness and invisibility of the watermark, this paper chooses the low frequency sub-image of the two level wavelet decomposition for the watermark information embedded, as shown in Fig.1, and uses the SVD to enhance the imperceptibility of watermark. The performance of watermark embedding is greatly affected by the wavelet base. In order to obtain good performance, the Haar wavelet is adopted by the Ref.[5].

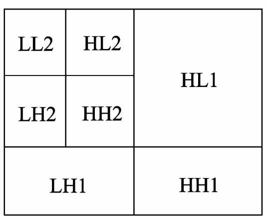

Fig.1 Schematic diagram of two-level wavelet transformation structure

1.2 Singular value decomposition (SVD)

SVD of numerical analysis is a kind of matrix diagonalization algorithm[6]. From the angle of linear algebra, a gray image can be regarded as a nonnegative matrix[7]. If an image is expressed as $\boldsymbol{A}$, and defined as $\boldsymbol{A} \in \mathbf{R}^{M \times N}$, where $\mathbf{R}$ represents the real number field. The matrix singular value decomposition is defined as

$$\boldsymbol{A} = \boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^T, \tag{1}$$

where $\boldsymbol{U}$ and $\boldsymbol{V}$ are orthogonal matrix while $\boldsymbol{S}$ is a diagonal matrix; the diagonal elements of $\boldsymbol{S}$ are called singular values of $\boldsymbol{A}$ and satisfy $\sigma_1 \geqslant \sigma_2 \geqslant \cdots \geqslant \sigma_i \geqslant \cdots \geqslant \sigma_M \geqslant 0$.

$\boldsymbol{U}\boldsymbol{S}\boldsymbol{V}^T$ is called decomposition of $\boldsymbol{A}$. Singular value shows the intrinsic character of the image; the first singular value is much larger than the other singular values in the image. Those singular values of the image are very stable, and there will be a little change after a small perturbation[8]. Block singular value decomposition will produce larger numerical singular value, which is in favor of the watermark embedding. It is these characters that guarantee the feasibility, invisibility and good robustness of the watermark.

2 Embedding and extraction of water-mark

2.1 Watermark embedding

1) To make two-level wavelet decomposition for the image, three high frequency sub-bands HH, LH, HL and a low frequency sub-band LL will be adopted. The low frequency sub-band image can also be divided into $m \times n$ blocks, while the maximum number of watermark bits can be embedded in the low-frequency sub-band image is: round $(M/2m) \times$ round $(N/2n)$. The watermark can not be embedded in the image, if the number of pixels in watermark exceeds this value. Then the operator must transform the watermark and reduce the amount of pixels.

2) To make singular value decomposition (SVD) for each sub-block, $Block_i = \boldsymbol{U}_i\boldsymbol{S}_i\boldsymbol{V}_i^T$ and the singular values in descending order.

3) To modify the value of $\boldsymbol{S}_1$ in each block according to the following rules ($Z = \mathrm{mod}\boldsymbol{Q}$):

① if $W_{(i,j)'} = 1$,

$$\begin{cases} \sigma_1' = \sigma_1 - Z - q/4, \text{ if } Z < q/4, \\ \sigma_1' = \sigma_1 - Z + 3q/4, \text{ else.} \end{cases} \tag{2}$$

② if $W_{(i,j)'} \neq 1$,

$$\begin{cases} \sigma_1' = \sigma_1 - Z + q/4, \text{ if } Z < 3q/4, \\ \sigma_1' = \sigma_1 - Z + 5q/4, \text{ else.} \end{cases} \tag{3}$$

where q is the embedding strength factor. The watermark information is embedded in the corresponding block $W'_{(i,j)}$, and the watermarked block is $Block_i' = \boldsymbol{U}_i\boldsymbol{S}_i'\boldsymbol{V}_i^T$.

4) To repeat 2), 3) until all the watermark information is embedded in the image.

5) To make inverse wavelet transformation on the low frequency sub-blocks which has embedded watermark information, the watermarked image is obtained.

2.2 Watermark extraction

The watermark extraction is the inverse process of embedding. The greatest advantage of the algorithm is that we can extract the watermark without using the original image. The extraction processes are as follows:

1) To make two level wavelet decomposition for the image which will be detected, and then to divide the low-frequency band images into $m \times n$ blocks.

2) To make singular value decomposition (SVD) for each block, $Block_i^{'} = \boldsymbol{U}_i\boldsymbol{S}_i^{'}\boldsymbol{V}_i^T$, and the singular values in descending order.

3) To extract the watermark information according to the following rules:

$$\begin{cases} W_{(i,j)}^{'} = 1, \text{ if } Z > q/2, \\ W_{(i,j)}^{'} = 0, \text{ else.} \end{cases} \tag{4}$$

4) To repeat 2) and 3), until all the watermark information embedded in the low frequency blocks is extracted.

3 Experimental results

The experimental platform is Matlab7.0 and the image of Lena (512 × 512) which is used in the experiment belongs to the system. The watermark image is grayscale image of 32×32. First, the operator must make two level decomposition of the image with the Haar wavelet base, and divide the sub-graph image into 32 × 32 blocks to make singular value decomposition for the sub-graph and embed the watermark image. SVD quantization factor Q in this article is 0.5. Fig.2 is the original image and Fig.3 is the watermark image. There is no obvious difference between two images from the visual effect, which show the algorithm has a good character of imperceptibility.

Fig.2 The original image

Fig.3 The watermark image

In order to validate the robustness of the algorithm, attacks of JPEG compression, noise and shear will be used to the watermark image. After JPEG compression, the size of the watermark image is changed from 257 k to 40.4 k, but the extracted watermark is still clearly visible, as shown in Fig.5. The extracted watermarks of adding 0.005 Gauss noise and 0.02 salt and pepper noise on the watermarked image are shown in Figs.6–7. The distortion of watermark is related to the noise intensity in the noise attack. After cutting the watermark image, the extracted watermark is shown in Fig.8. By comparison Fig.3 with Fig.4, the positions of the watermark distortion are the same as the shear attack position in the Fig.8. So there is no watermark information loss in the rest area of the image.

Fig.4 Image watermarking

Fig.5 Diagram of compressed image and extracted watermark

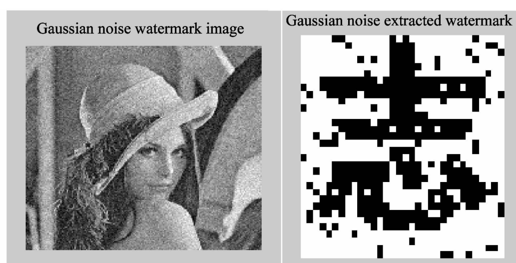

Fig.6 Diagram of the Gauss noise image and extracted watermark

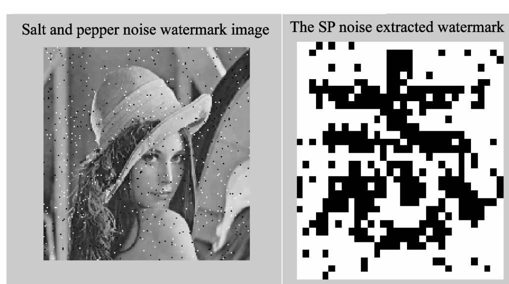

Fig.7 Diagram of the salt and pepper noise image and extracted watermark

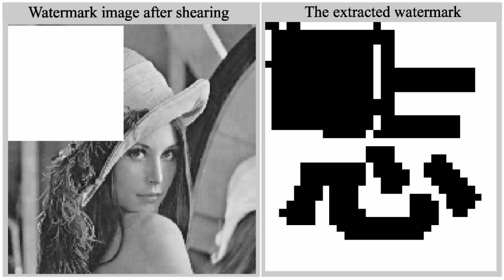

Fig.8 Diagram of 1/4 image sheared and extracted watermark

The peak signal to noise ratio (*PSNR*) is used to measure the change degree between original image and watermark image. At the same time, *NC* is used to measure the correlation between the original watermark and the watermark extracted[9,10]. The calcumation results are shown in Table 1.

Table 1 Calculation results

	PSNR	NC	
		Article	Ref.[11]
Add watermark	46.742 60	0.961 54	0.826 40
SP0.02	28.083 60	0.955 04	–
SP0.002	–	–	0.975 10
GS0.005	29.005 30	0.953 25	0.826 40
Shear 1/4	18.322 00	0.998 90	–
Shear 70×70	–	–	0.862 10

PSNR is

$$PSNR = 10\lg\left[\frac{M\times N\times \max(F(i,j))^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}[F'(i,j)-F(i,j)]^2}\right]. \quad (5)$$

NC is

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}F'(i,j)\times F(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}F'(i,j)^2}\times\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}F(i,j)^2}}. \quad (6)$$

There is a high correlation between the watermark image and the original image by verification. The algorithm has a strong resistance for common attacks, which can also be extracted after the watermark information attacked. The extraction method of the embed watermark is simple, convenient and practical.

4 Conclusion

This paper makes full use of multi-resolution image intrinsic characteristics of SVD and DWT, and puts forward a new kind of blind watermarking algorithm based on SVD in the wavelet domain. The experimental results show that the algorithm has strong robustness for the noise, compression and shear attacks, and can improve the capacity of image against coalition attacks. The watermark extraction is simple, and does not need the original image. There is no encryption or scrambling for the watermark image. The algorithm needs to be improved in the security of the watermark information.

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基于小波变换与奇异值分解的图像盲水印算法

轩春青[1]，轩志伟[2]，张　霞[2]，陈保立[2]

（1. 郑州成功财经学院 信息工程系，河南 巩义 451200；2. 中北大学 仪器与电子学院，山西 太原 030051）

摘　要： 本文提出了一种新的基于离散小波变换(DWT)与奇异值分解(SVD)相结合的数字图像盲水印算法。该算法首先将原始图像作小波分解并将小波分解得到的低频子带进行分块，再对每一块进行奇异值分解，然后选取每块中最大的奇异值通过量化的方法嵌入水印信息，而且水印的提取不需要原始图像。实验结果表明，该算法具有一定的不可感知性及鲁棒性。

关键词： 离散小波变换；奇异值分解；盲水印算法；鲁棒性

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