DWT and SVD based Watermarking Scheme with Circulation

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***Abstract*—The major application for watermark is protecting intellectual property rights. In this paper, a watermark scheme with circulation, based on non-overlapping discrete wavelet transform (DWT) and singular value decomposition (SVD), is presented. First, the original host image and watermark image are divided into non-overlapping blocks, respectively and to the former DWT and SVD is applied. Second, the scrambling watermark by Chebyshev chaotic map is embedded into the singular value matrix of original components with circulation. Extracting any consecutive four rows and columns from the blocked watermarked image can get complete watermark information. The quantity of embedded watermark information is large and the original image is not needed for watermark extracting. Both theoretical analysis and experimental results indicate that the proposed method can very effectively resist large degree of geometric attacks and compound attacks, and it is also strongly robust against common image processing attacks.**

***Index Terms*—Intellectual property rights, Circulation, Chebyshev chaotic map, Singular value decomposition**

I. INTRODUCTION

Because the digital products are easy to copy, modify and embezzle, how to protect copyright of digital products has become a great challenge. Digital watermarking is an effective means for copyright protection and authentication of digital media data, which has attracted much attention in recent years. It allows owners to hide their ownership rights and access controls into their original images. The watermark can be various data formats such as logos, tags, sound or any other copyright information. This implies that the watermark should be robust against most common attacks such as rotation, scaling, cropping, noise and JPEG compression. Basic properties of a digital watermarking technique are imperceptibility, robustness and the ability to provide a definite proof of ownership [1-5].

Recently, one kind of watermarking, which is based on DWT and SVD, is popularly proposed. The DWT approach remains one of the most effective ways for image watermarking. The wavelet functions will analyze image features such as edges and borders through good space-frequency localization [6-8]. SVD performs an optimally matrix decomposition in a least-square domain for matrices in real number domain [9-12]. A blind extraction method for gray image watermark based on DWT and SVD was proposed in [13], first, one binary watermark image was embedded into the host image using the technology of wavelet transform and singular value decomposition and then the fragile watermark was further embedded into LSB of the above watermarked image to reduce the fragile watermark's influence towards robustness. Although, the combination of the two watermarks achieves a double protection for the host image but how to solve the large calculation amount is a problem. Y. J. Cai et al[5] proposed a technique in which each bit of the scrambling watermark was embedded into the relative size of the first singular values of one couple blocks, which was the non-overlapping blocks of host channel implemented by DWT and SVD. H. H. Tsai et al [14] hide a watermark bit in the low-low (LL) sub-band of a target non-overlap blocks of the host image by modifying a coefficient of U component on SVD version of the block. A digital image watermarking algorithm using DWT and singular value decomposition was proposed in reference [15], the watermark is not embedded directly on the wavelet coefficients but rather than on the elements of singular values of the cover image’s DWT sub-bands. Reference [16] suggested a gray-scale watermark algorithm based on SVD, the pixel value of watermark is embedded into the blocks of largest singular value by the quantization. Chen et al. [17] proposed a wavelet-based copyright protection method via constructing a master share by comparing the coefficients in a low-frequency sub-band with the average of them. An ownership share is constructed by applying XOR operation to the secret image and master share. Their method is robust against commonly used image manipulations except cropping and rotation. Wang et al [18] introduced a hybrid DWT-SVD copyright protection scheme, in which the features of a host image are extracted first by applying the DWT and the SVD. The extracted image features are then classified into two clusters by utilizing the k means clustering method, and a master share is generated according to the clustering result, then the master share and a secret image are used to construct an ownership share according to a two-out-of-two VC technique. The above algorithm achieves strong robustness against common image processing attacks, such as blurring, sharpening, noise addition and JPEG compression.

Based on the methods above, a novel blind circular digital watermark method based on DWT and SVD was

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presented in this paper. Firstly, the watermark image was scrambled by Chebyshev chaotic map and then was blocked to non-overlapping 2^4 groups. Secondly, the original image was decomposed eleven components by 3-DWT and the low-low channel was divided into equally non-overlapping blocks and implemented with SVD, respectively. Thirdly, every scrambling watermark blocks were embedded into the singular value matrix of original blocks with circulation.

The rest of this paper is organized as follows. The proposed watermarking scheme is depicted in section 2. The detailed watermark embedding and extraction procedures are presented in Section 3. Subsequently, Section 4 we present our numerical simulations including the robustness to several possible attacks. Finally, conclusions are given in Section 5.

II. Related Work

A. Chebyshe Maps

Chebyshev maps have important properties of excellent cryptosystem. The expression of Chebyshev maps as in (1).

$$X_{n+1} = \cos(k \cos^{-1} X_n) \qquad -1 \le X \le 1 \tag{1}$$

Where k is the degree of Chebyshev maps, if $k \geq 2$, the Lyapunov exponent of Chebyshev maps is positive, which predicates that Chebyshev maps are chaotic. Its invariant probability distribution density is as in (2).

$$\rho(X) = 1 \Big/ (\pi\sqrt{1-X^2}) \tag{2}$$

Chebyshev maps are a classic chaotic system with the sensitivity of initial state, the real number sequences generated by which are orthogonal each other. The auto-correlation function of real-valued sequences generated by the Chebyshev maps is δ function. Moreover, it can generate a huge number of different sequences using only slightly different initial values. The parameter k and initial state value X_0 are regarded as the key of proposed watermarking system. Chaotic maps generated by a single real-valued chaotic sequence cycle from initial value X_0 are limited. To avoid this situation, several chaotic sequences are cascaded to generate longer period of ones. The first chaotic sequence X_1, which length is N_1, was generated by initial value X_0 and then the second chaotic sequence X_2, which length is N_2, was generated by initial value X_1, will analogize in turn. The complexity of chaotic system is decided by the level of cascaded. According to the computation, the system use two cascading chaotic sequence. Since the binary sequence is used as a spreading sequence in actual digital spread spectrum communication system, to take 0 as the threshold value, using threshold approach to binary chaotic sequence as in (3).

$$sgn(X) = \begin{cases} 1 & x \in [0,1] \\ -1 & x \in [-1,0] \end{cases} \tag{3}$$

Given a set of initial values, computing with (1) can get a certain length of real-valued sequences, threshold with (3) then obtained binary chaotic spreading sequence group.

B. Choice of Embedding Position

Wavelet is a very important and useful tool for signal analysis and processing at multiple resolutions. The algorithm embeds the watermark in the low-frequency approximation sub-band (LL), for which is less sensitive to some image-processing operations, such as image compression, than high-frequency components. On the other hand, the human visual system is more sensitive to image modifications in smooth areas (low-frequency components) than texture and edges areas (high-frequency components). To achieve image imperceptibility and robustness a trade-off is made where each bit is embedded by modifying several DWT coefficients of the LL sub-band. The increased redundancy leads to increased robustness and, at the same time, allows the modifications of the DWT coefficients to be only small, leading to better imperceptibility.

C. Singular Value Decomposition

SVD is an important tool in linear algebra, which is widely applied in many research fields such as principal component analysis, canonical correlation analysis and data compression. From the perspective of linear algebra, a digital image can be viewed as a matrix composed of a number of nonnegative scalars, singular value decomposition (SVD) belongs to an orthogonal transformation, it can make the image matrix diagonalization. Let $X \in R^{m \times n}$ denote an image matrix, two orthogonal matrixes: $U=[u_1, u_2, u_3, \cdots, u_m] \in R^{m \times m}$ and $V=[v_1, v_2, v_3, \cdots, v_n] \in R^{n \times n}$, there exist a factorization of the form as (4)

$$X = USV^T \tag{4}$$

Where $S \in R^{m \times n}$ is a matrix of all elements are zero except for its diagonal elements, u_i and v_i are called the singular value vectors and the diagonal elements shown as (5)

$$\lambda_1 \ge \lambda_2 \ge \lambda_3 \ge \cdots \ge \lambda_r \ge \lambda_{r+1} = \cdots = \lambda_N = 0 \tag{5}$$

Where r is rank of X, λ_i (i=1, 2, ⋯, N) is uniquely determined by the SVD and called the singular values of X. Use of SVD in digital image processing has some advantages. First, the size of the matrices from SVD transformation is not fixed. It can be a square or a rectangle. Secondly, singular values in a digital image are less affected if general image processing is performed because bigger singular values not only preserve most energy of an image but also resist against attacks. Generally, the matrix S has many small singular values. Finally, singular values possess intrinsic algebraic image properties.

D. System of Circulation

In this work, we propose a novel method with circulation to embed and extract watermark information. The main procedure includes three steps as follows.

Step1: The watermark image is equally divided into non-overlapping p×p blocks W_t (t=0,1, 2, ···, p^2-1) and p is a positive integer.

Step2: The original image is equally divided into non-overlapping m×n blocks A_{ij} (i=0,1, 2, ···, m-1) (j=0, 1, 2, ···, n-1), m is an integer multiple of p.

Step3: Modifying the Singular value to embed the watermark information with circulation and get new value. Each watermarking block was embedded into one original block. The first column of every row of original image matrix A_{ij} was embedded with W_t ($t=(i \bmod p)\times p$) and the next column was embedded with $W_{((t++) \bmod p^2)}$ where mod denotes module operation.

For example, the watermark image was divided into non-overlapping 4×4 blocks W_t (t=0, 1, 2…15) and the original image was blocked to non-overlapping 8×16 blocks Aij, (i=0, 1, 2…7) (j=0, 1, 2…15) (shown as in Fig. 1). Every box represents one carrier image block and the symbol W_t (t=0, 1, 2…15) denote watermark block. Extracting any consecutive four rows and columns shown as the coloring regions can get complete watermark information from the embedded blocks. That is why the algorithm can effectively resist the cropping attacks.

W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}
W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_0	W_1	W_2	W_3
W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7
W_{12}	W_{13}	W_{14}	W_{15}	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}
W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}
W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_0	W_1	W_2	W_3
W_8	W_9	W_{10}	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7
W_{12}	W_{13}	W_{14}	W_{15}	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}	W_{11}

Figure 1. System of circulation.

III. WATERMARK EMBEDDING AND EXTRACTION

Let O be the original image of size M×M, W is the watermark image of size N×N. The relation between original image and the watermark image meets $O=2^k \times W$, the sizes of O are integer multiple of W, where k is positive integer. The proposed method in this paper is illustrated in Fig. 2.

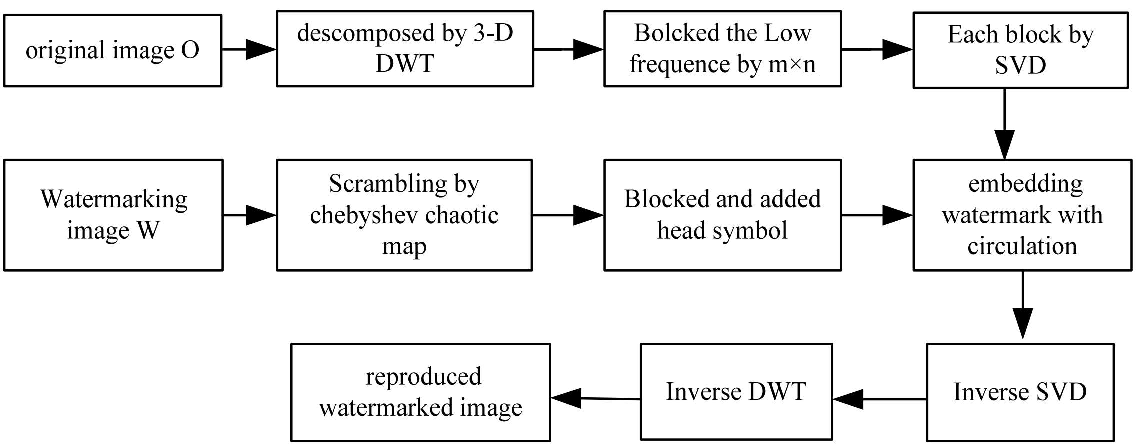


Figure 2. Watermark embedding process.

The concrete embedding procedure is as bellows:

Step1: W is encrypted by Chebyshev chaotic maps using (1) for taking the initial value X_0 to get $N_1 \times X_1$. (N_1 is the length of scrambling sequence X_1)

Step2: Setting X_1 as new initial value by Chebyshev chaotic maps again get X_2 which length is $N_1 \times N_2$.

Step3: Get encrypted watermark W' by using threshold approach to binary chaotic sequence in (3) for all of the X_2

Step4: Partition the W' into a set of non-overlapping equally blocks with size W'_d (d=0,1,…,15).

Step5: Perform 3-level DWT for an original image O with size $M \times M$ and get the LL3 sub-band.

Step6: Partition the LL3 sub-band into a set of non-overlapping equally blocks $LL3_{ij}$ with size O_{ij}.

$$O_{ij} = {(M \times M)} \Big/ {2^n \times 2^4} \tag{6}$$

Where n is a positive integer.

Step7: Apply SVD for decomposing each block $LL3_{ij}$ using (4) to get three components U_{ij}, S_{ij}, and V_{ij}.

Step8: The encrypted watermark W'_d, which being added heading symbol to identify its order, is embedded into the singular value matrix S_{ij} using the (7) with circulation as shown in Fig. 2.

$$S'_{ij} = S_{ij} + \alpha W'_d \tag{7}$$

Where α is the scale factor, it is used to control the watermark embedding strength, S_{ij}' is singular value matrix of the watermarked image.

Step9: Perform inverse SVD for U_{ij}, S_{ij}' and V_{ij} to recover $LL3'_{ij}$ sub-band and rearrange the watermarked blocks back into one matrix to build the watermarked LL3.

Step10: Perform the inverse 3-level DWT to get the watermarked image O'.

Watermark extraction is the reverse procedure of watermark embedding (shown as Fig. 3).

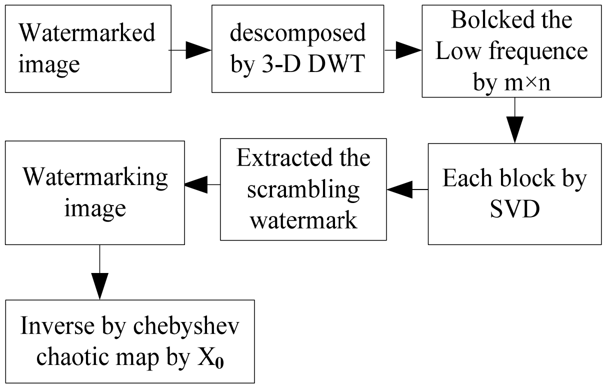


Figure 3. Watermark extraction process.

Step1: Perform 3-level DWT for watermarked image with size $M \times M$ and get the LL3 sub-band.

Step2: Divide the low LL3 sub-band into non-overlapping blocks having the same size used in the embedding process.

Step3: Perform SVD on the blocks $LL3'_{ij}$ from any consecutive four rows and columns to get the components S'_{ij} by use (8).

$$S'_{ij} = U'_{ij} V'_{ij} X^T \tag{8}$$

Step4: Extracting scrambling watermark information from every S'_{ij} by (9).

$$W'_d = {(S'_{ij} - S_{ij})} \Big/ {\alpha} \tag{9}$$

Step5: Rearrange watermark components to reproduce the scrambling watermark image by the head symbol embedded in every W'_d.

Step6: Perform threshold approach to revere chaotic sequence and reconstruct the watermark W by Chebyshev chaotic maps with initial value X_0.

Figure 4. Original images (the first line) Watermarked images (the second line).

IV. Experimental Results

In order to study the sensitivity of this watermarking method for different images and sizes, we have used four sets original images in the simulations, such as Fishing-boat, Baboon, Lena and Peppers, respectively. The sizes of original images in the experiences are 512×512 and the block sizes are 8×8, 16×16 and 32×32, respectively. Several experiments are presented to demonstrate the performance of the proposed approach. Some of these original images with their watermarked images have, respectively, been shown in Fig. 4. The watermark image of size 32×32 and the block sizes are 4×4 (shown in Fig. 5). It is virtual impossible to distinguish the differences between the original image and the watermarked image from visual effect.

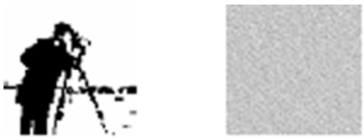


Figure 5. Watermarking image Scrambling watermarking image.

Normalized correlation (NC), a similarity indicator specified in (10), is used to evaluate the similarity between the original watermarking W and the extracted watermarking W' retrieved from an attacked and watermarked image.

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left|W + W'\right| \div 2}{M \times N} \qquad (10)$$

Where M and N represent the length and width of the watermark image, respectively, higher NC value stands for high resemblance between W and W'. Additionally, another quantitative index, Peak Signal-to-noise (PSNR) is used to evaluate the quality of the watermarked image to the original image. The higher PSNR value indicates a watermarking method produces few differences between original image and watermarked image. The different PSNR of watermarked images Lena by 8×8, 16×16 and 32×32, respectively were shown in table 1.

TABLE I
PSNR OF WATERMARKED IMAGES OF LENA WITH DIFFERENT SIZES

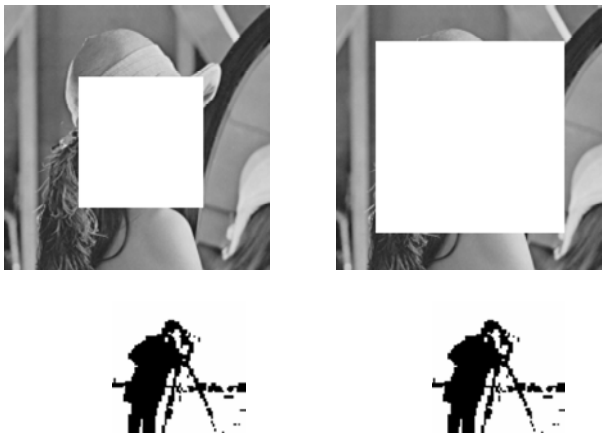
Watermarked images	PSNR		
	8×8	16×16	32×32
Fishingboat	39.258	37.238	36.824
Baboon	38.964	37.362	35.987
Lena	38.769	38.247	35.898
Peppers	39.946	38.462	36.163

For the sake of clarity and simplicity, only one original image blocked by 16×16, Lena is used for analysis in the following discussion.

A. Cropping Attacking

Image cropping is very frequently used in real life, which is a lossy operation. Too much cutting will make the image meaningless and unvalued, so the degree of cropping attack will not be much in the general case. Four different cropping attacks are carried out to the watermarked image, respectively. The experimental results are shown in Fig. 6. The proposed algorithm is resistant to a large extent cropping attack, which has wonderful performance in the experiments.

(a) (b)



(c) (d)

Figure 6. (a) Watermarked image cutting quarter and extracted watermark (b) Watermarked image cutting half and extracted watermark (c) Watermarked image cutting quarter in center and extracted watermark (d) Watermarked image cutting half in center and extracted watermark.

B. Scaling Attack

The great majority of watermarking algorithm resist against scaling attack in the interval [0.5, 2], but the proposed algorithm can be resistant to any size scaling attacks. The watermarked image to zoom in and out and the extracted watermarking image are shown in Fig. 7.

C. Aspect Ratio Adjustment Attack

In some applications, the watermarked image may be stretched more in one spatial dimension than another. This type of distortion is sometimes referred to as aspect ratio adjustment. The most watermarking algorithm can not resist against aspect ratio adjustment attack, the

Figure 7. Enlarged watermarked image and extracted watermark (ratio is 3) Reduced watermarked image and extracted watermark (ratio is 0.4).

proposed scheme in this paper has strong robust against that one. Fig. 8 shows the watermarked images stretched by width or height and the extracted watermarks. The results indicate that the extracted watermarks are originally the same as the embedded watermark, which has stretched by the same way.

(a) (b)

Figure 8.(a) Watermarked image (height stretched to 1.5 times) and extracted watermark (b) Watermarked image (width stretched to 1.5 times) and extracted watermark.

D. Conventional Attack

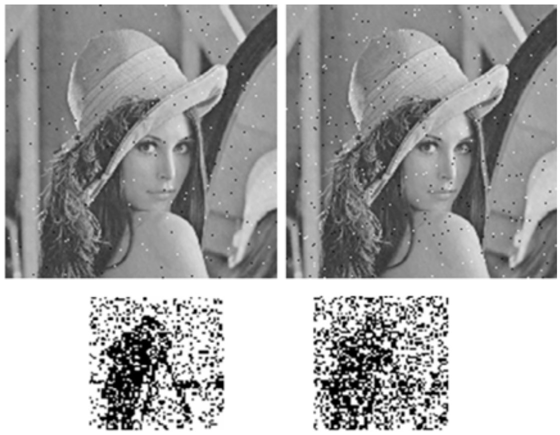
The most common manipulation in digital image is filtering. The extracted watermarks, after applying median filtering and Gaussian low-pass filtering, are shown in the Fig. 9 (a) and (b). It can be observed that after applying these filters, the extracted watermark is still recognizable.

Addition of noise is another method to estimate the robustness of the watermark. Generally, addition of noise is responsible for the degradation and distortion of the image. The watermark information is also degraded by noise addition and results shown some difficulties in watermark extraction. Fig. 10 shows the results of adding Pepper-and-Salt noise with 0.005 and 0.01 to the watermarked Lena image. The embedded watermark can be exacted and detected from the watermarked image of added Pepper-and-Salt noise. It can be observed that extracted watermark (shown in Fig. 10 (b)) is a noisy image, which nearly can not be recognizable.

To check the robustness against Image Compression, the watermarked image is tested with JPEG compression attacks. We show the watermark extracted from JPEG compressed Lena image with various quality factors (QC). Briefly, JPEG quality factor is an indication of the distortion, such that 100% quality factor corresponds to least distortion. Table 2 gives NC values of different QC under JPEG compression. It is variously that the algorithm is strongly resistant to JPEG compression.

(a) (b)

Figure 9. (a) Watermarked image and retrieved watermark (NC=0.8788) under median filtering attack.
(b) Watermarked image and retrieved watermark (NC=0.9767) under Gaussian low-pass filtering attack.



(a) (b)

Figure 10. (a)Watermarked image and retrieved watermark (NC=0.8146) under Pepper-and-Salt noise attack (density=0.005). (b)Watermarked image and retrieved watermark (NC=0.6928) under Pepper-and-Salt noise attack (density=0.01).

TABLE II
RESULTS OF DIFFERENT QC UNDER JPEG COMPRESSION

QC (%)	100	80	70	60
NC	1	0.9989	0.9978	0.9963
QC (%)	50	40	30	20
NC	0.9881	0.9694	0.9044	0.76

V. CONCLUSIONS

In this paper, a blind watermark algorithm based on DWT-SVD and chaos with circulation was proposed. The proposed scheme takes advantage of image scrambling and blocked with circulation to improve the robustness and security of current watermark schemes. During the embedding procedure, the watermark is cropped into small watermarks by 4×4 and the original image blocked by 8×8, 16×16 and 32×32. Each small

TABLE III.

NC RESULT VALUES OF THREE IMAGES UNDER DIFFERENT ATTACKS

Attack type	Pepper NC			Baboon NC			Fishingboat NC		
	8×8	16×16	32×32	8×8	16×16	32×32	8×8	16×16	32×32
Cutting quarter	0.9999	1.0000	0.9989	0.9994	0.9999	1.0000	0.9957	0.9993	1.0000
Cutting half	1.0000	0.9999	0.9994	1.0000	1.0000	0.9999	1.0000	0.9997	1.0000
Cutting quarter in center	0.9012	1.0000	0.9998	0.9137	0.9989	1.0000	0.9027	0.9984	1.0000
Cutting half in center	0.8937	0.9999	1.0000	0.8896	0.9979	1.0000	0.9026	0.9921	1.0000
Aspect Ratio Adjustment height to 2 times	1.0000	0.9996	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Aspect Ratio Adjustment width to 2 times	1.0000	1.0000	0.9994	1.0000	0.9999	0.9999	1.0000	1.0000	0.9999
Scaling Attack ratio is 4	0.9999	1.0000	1.0000	1.0000	0.9999	1.0000	0.9999	1.0000	1.0000
Scaling Attack ratio is 0.3	1.0000	0.9998	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
JPEG QF=90	0.9998	0.9987	0.9993	0.9974	0.9958	0.9948	0.9939	0.9927	0.9971
JPEG QF=30	0.9012	0.8847	0.9042	0.9037	0.9159	0.9201	0.9063	0.9076	0.9215
JPEG QF=20	0.7658	0.7485	0.7685	0.7834	0.7923	0.8013	0.8042	0.7968	0.8016
Median filtering 5×5	0.8812	0.8914	0.8793	0.8794	0.8921	0.8855	0.8936	0.8794	0.8658
Gaussian low pass filtering 5×5	0.9812	0.9831	0.9764	0.9851	0.9785	0.9836	0.9862	0.9784	0.9819
Pepper and Salt noise 0.005	0.8146	0.8146	0.8016	0.8159	0.8204	0.8177	0.8094	0.8209	0.8057
Pepper and Salt noise 0.01	0.7283	0.7128	0.7349	0.7217	0.7017	0.7341	0.7058	0.7192	0.7303

block of watermark is embedded into one single blocked with circulation. The perceptual quality and the watermarking capacity are greatly improved by this way. The original image is not needed during the extraction and detection procedure. Experimental results and attacks analysis show that the watermark algorithm is transparent and robust against some image processing operations, such as JPEG compression, median filtering, additive noise and some cropping attacks. The deficiency of the algorithm is consistency between extraction and embedment, in which the blocks must be implemented in the same manner. Otherwise, the watermark cannot be correctly detected.

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