A Dual Color Image Watermarking Scheme Based on Non-overlapping Blocks with Circulation

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***Abstract*—Digital watermarking is a method for protecting copyrighted materials such as digital images. This paper introduces a new color watermarking scheme based on non-overlapping Singular Value Decomposition (SVD) with circulation. First, dual color host image and watermark are decomposed into R, G and B components, respectively. Scrambling the three components of watermark by Arnold chaotic map and divided them into *b×b* non-overlapping blocks, respectively. The three components of original image are divided into equally-size and non-overlapping blocks. Second, performing an SVD transformation on all of blocks, the singular values (SVs) of each watermarking block are added to each SVs of original same color block separately with circulation. Extracting any consecutive *b* rows and *b* columns of watermarked image blocks can get complete watermark information. Experimental results show the proposed scheme can effectively resist large degree of geometric attacks and compound attacks, and it is also strongly robust against common image processing attacks.**

***Index Terms*—Copyrighted materials, Circulation, Arnold chaotic map, Singular value decomposition**

I. Introduction

Due to the rapid growth in the use of digital media, there is an increasing concern about unauthorized handling, copying and reuse of information. In general, digital watermark techniques must satisfy the following two requirements. First, the embedded watermark should be perceptually invisible and should not visually distort the host image. Second, the embedded watermark should be hard to remove. Schemes of embedding digital watermarks into grayscale images have been researched and developed greatly [1-3].

In recent years, encryption and hiding for color images have been noticed and developed steadily, since color images provide more information than monochromatic ones [4-5]. Also, to some extent the color information can offer a higher security level than binary and gray images. The watermarking scheme proposed by Kutter was the first work to be explicitly designed for color images [6]. And then many significant works about color image encryption and hiding have been produced [7-10]. Mei et a1 [11] proposed a scheme of hiding a binary watermark information in the low frequency coefficients of 8×8 discrete cosine transform(DCT) blocks of the red, green and blue components. Banf et a1 [12] proposed a scheme in which the red, green and blue channels were transformed by full frame DCT, and selected to hide watermark. Embedding color watermarks in color images was proposed in reference [13], color watermarks are embedded by modifying quantization indices of color pixels without resulting in perceivable distortion. Only a few information including the specification of color gamut, quantizer step size and color tables are required to extract the watermark. Q.T. Su et a1 [14] proposed a technique in which using the Schur decomposition to embed color image in color image and extract watermark in the blind manner. Since Schur decomposition is an intermediate step in SVD decomposition, the proposed method needs fewer number of computations. A blind dual color images watermarking based on IWT and state coding in [15] was proposed, in which R, G and B components of color watermark are embedded to Y, C_r and C_b of color host image. Although DCT and DWT are the mostly used transform methods, the SVD transform has been significantly used in recent watermarking schemes. Liu et al have proposed an SVD based watermarking scheme in which the watermark is added to the SVs of the whole image or parts of it [16]. A single watermark is used in this scheme which may be lost due to attacks. Mohammad[17] propose an improve algorithm for Liu's document, which partition the original image into M×M blocks and embed one bit of the watermark in each block. Mohammad's algorithm, one watermark is distributed into all the blocks of the original image, which is difficult to resist a wide range of cropping.

In summary, to avoid the disadvantage in ref [17], a novel dual color image watermarking scheme with circulation based on SVD is presented. First, each channel of the color watermark and original image are decomposed into R, G and B components, respectively. Second, the three watermarking color components are scrambled by Arnold chaotic map and divided into non-overlapping $b\times b$ blocks, respectively. Third, each channel of the original image is divided into blocks and

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performed an SVD on them. Finally, we add SVs of the scrambled watermark block to the SVs of every suiting block obtained from block-SVD on the host image in each identical of RGB channels respectively 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. 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 viewpoint of image processing applications, there are two main properties of the SVD. First, the SVs of an image have a good stability, i.e., when a small perturbation is added to an image, its SVs do not change significantly. Second, SVs represent intrinsic algebraic image properties.

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 (1)

$$X = USV^T \tag{1}$$

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 (2)

$$\lambda_1 \ge \lambda_2 \ge \lambda_3 \ge \cdots \ge \lambda_r \ge \lambda_{r+1} = \cdots = \lambda_N = 0 \tag{2}$$

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. Second, 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 has many small singular values.

B. System of Circulation

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

Step1: The watermark image are equally divided into non-overlapping $b\times b$ blocks W_t (t=0, 1, 2, ⋯, b^2-1) and b is a positive integer ($b \geqslant 2$).

Step2: The original image are equally divided into non-overlapping $m\times n$ blocks A_{ij} (i=0, 1, 2, ⋯, m-1) (j=0, 1, 2, ⋯, n-1), m is an integer multiple of b and $n \ge b$.

Step3: performing an SVD transformation on all of blocks, the SVs of each watermarking block is added to one SVs of original block under circulation.

The first column of every row of original image matrix A_{ij} was embedded with W_t (t= (i mod b)×b)) and the next column was embedded with $W_{((t++) \bmod b^2)}$. Wherein *mod* denoting module operation.

As an example, the watermark image is divided into non-overlapping 4×4 blocks W_t (t=0, 1, 2…15) and the original image is blocked to non-overlapping 8×16 blocks A_{ij}, (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) denotes watermark block. Extracting any consecutive four rows and columns shown as the coloring regions can get complete watermark information from watermarked image. That is why the algorithm can effectively resist a wide range of 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_1	W_2	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 color image of size M×N, W is the watermark color image of size B×B. 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.

The concrete embedding procedure is as bellows:

Step1: Based on the theory, that a RGB color image is the composition of R, G and B of three components. The color watermark image W and original image O are partitioned into three components R_W, G_W, B_W and R_O, G_O, B_O by dimension reduction treatment, respectively.

For the sake of simplicity and clarity, only the green component is illustrated as follows.

Step2: Partition the G_O into a set of m rows and n columns non-overlapping blocks with size O_{ij}.

$$O_{ij} = {(M \times N)}/{m \times n} \tag{3}$$

In which m and n are positive integer.

Step3: Performed an SVD on each block O_{ij}. Let the matrix X, with elements x_{ij}, i =0, 1, 2,⋯, m-1 and j =0,1, 2,⋯, n-1, represent the block O_{ij} which needs to be watermarked. We compute the SVD of X as bellows.

$$X = U_X S_X V_X^T = A_X V_X^T \tag{4}$$

Step4: Using the Arnold transformation to change the distribution of G_W and make it "mess". The changing number k_a is as a private key.

$$\begin{pmatrix} X' \\ Y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix} (\bmod P) \tag{5}$$

Where (X, Y) are the pixel of green watermark image, (X' , Y') are the pixel of corresponding scrambling image and P is the rank of digital image matrix.

Step5: Get encrypted watermark W'_G by using (5). Partition the W'_G into a set of equally-size and non-overlapping blocks $b\times b$ with W'_{Gd} and d ($d=b^2$) is the sum of watermark blocks.

Step6: The encrypted watermark W'_{Gd}, which being added sequence identification number. Let Q represent the matrix of the W'_{Gd} to be embedded. An SVD for Q as follows:

$$Q = U_Q S_Q V_Q^T = A_Q V_Q^T \tag{6}$$

Where $A_{X(Q)}=U_{X(Q)}S_{X(Q)}$ are also called the principal components in the language of principal component analysis. Now, we add the scaled eigenvector V_Q of watermark to that of the original image.

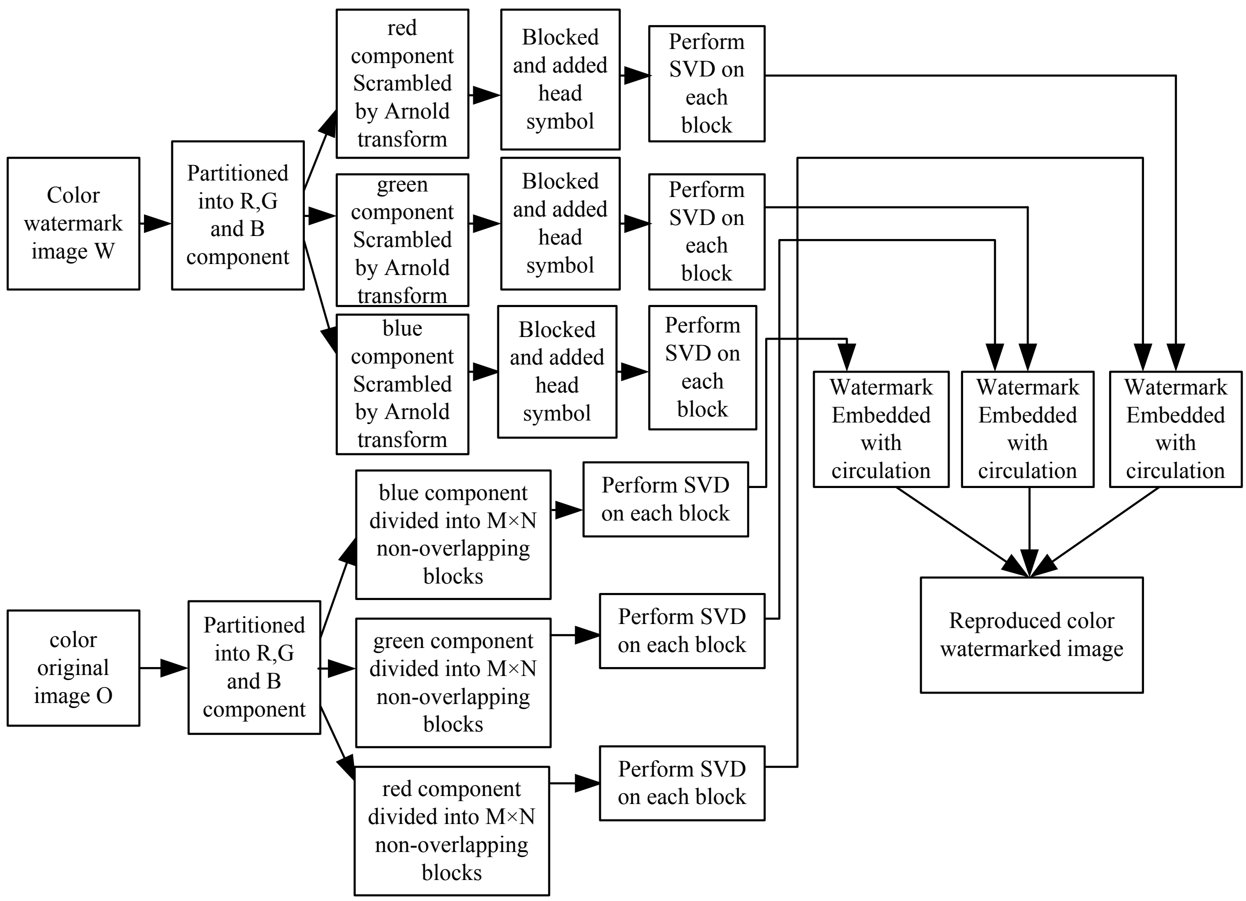


Figure 2. Watermark embedding process.

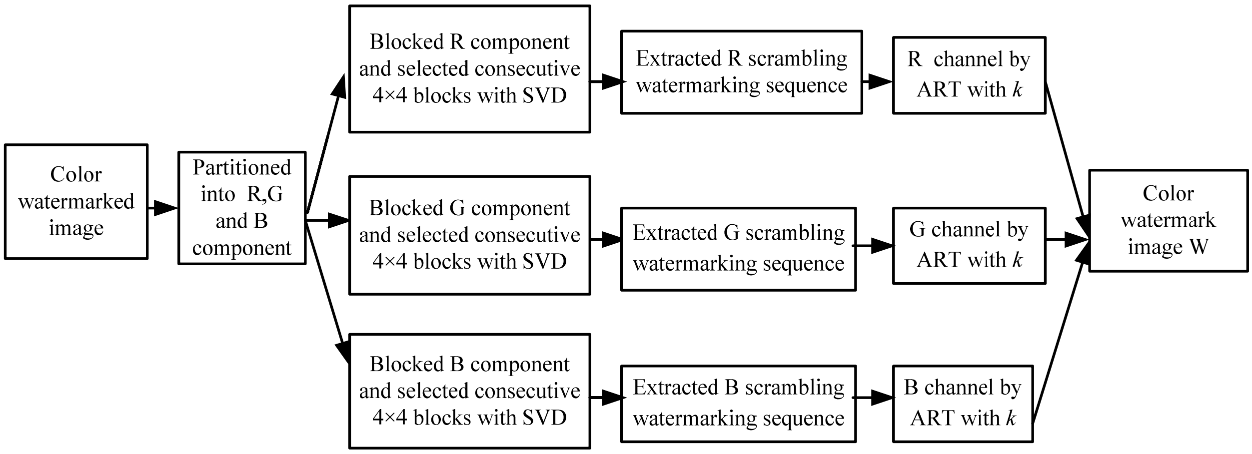


Figure 3. Watermark extraction process.

$$V' = V_X + \alpha V_Q \tag{7}$$

Where α is the scale factor, it is used to control the embedding strength of watermark.

Step7: Then the watermarked block is obtained by multiplying the matrix A_X and V'^T.

$$X' = A_X V'^T \tag{8}$$

Repeat step6-step7, until every green original block is embedded with one green watermark block as shown in Fig. 1.

Step8: Doing the same thing to the blue and red components, we can get the corresponding watermarked image of them.

Step9: Reproduced the watermarked R, G and B to rebuild the watermarked color image.

Extraction algorithm is a straightforward reversal of the embedding algorithm (shown as Fig. 3).

Step1: The watermarked color image is first partitioned into R, G and B components by dimension-reduction treatment.

Step2: Divide the watermarked components into blocks having the same size used in the embedding process.

Step3: Perform SVD on any consecutive b rows and b columns of three single color watermarked blocks to obtain the SVs of each one.

Step4: Obtains the matrices that contain the watermark using (4) and extract the possibly corrupted watermark block using the follows:

$$V_Q'^T = (A_X^{-1} X' - V_X'^T) \big/ \alpha \tag{9}$$

$$Q' = A_Q V_Q'^T \tag{10}$$

Step5: Rearrange watermark block components to reproduce the scrambling watermark image by the sequence identification number embedded in every W'_{Rd}, W'_{Gd} and W'_{Bd}.

Step6: The inverse Arnold transformation operation based on the private key k_a, we can get the extracted watermark W'_R, W'_G and W'_B of each component.

Step7: Reconstruct the three components of W'_R, W'_G and W'_B, which can be available to recover the watermark image.

IV. Experimental Results

In order to study the sensitivity of the proposed method, a series of different sizes and images are used to simulate. We have used four sets original images in the simulations, such as F16, Watch, Waterfall and Water, respectively. The sizes of original images in the experiences are 512×512 pixels and the block sizes pixels are 16×16, 32×32 and 64×64, respectively. Several experiments are presented to demonstrate the performance of the proposed approach. The color watermark image size is 32×32 pixels and the block sizes pixels are 8×8 shown as Fig.4. Some of these original images and their watermarked images have been shown in Fig. 5, respectively. It is virtual impossible to distinguish the differences between the original image and the watermarked one from visual effect.

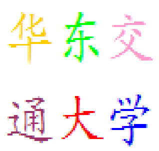


Figure 4. Watermarking image.

Figure 5. Original image.

Normalized correlation (NC), a similarity indicator specified in (11), is used to evaluate the similarity between the original watermarking W and the extracted watermarking W' retrieved from an attacked and watermarked image.

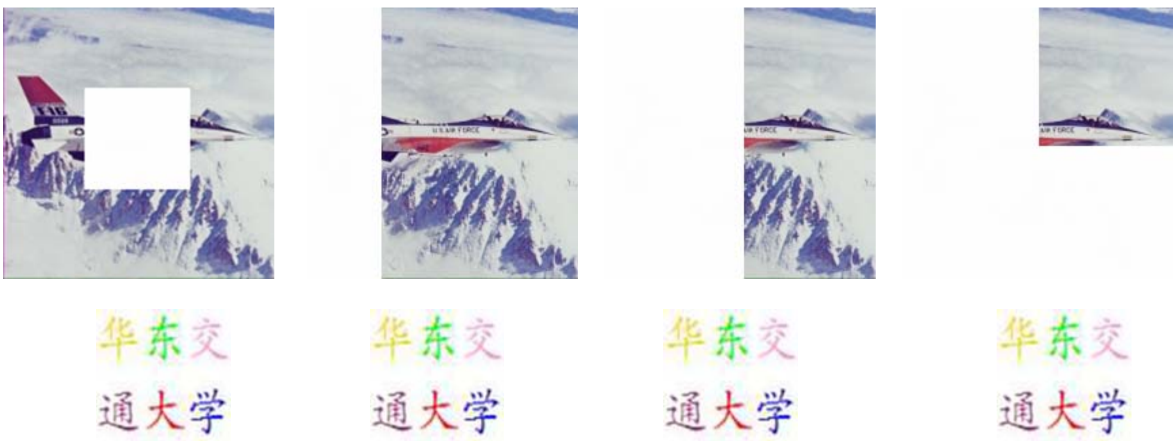
$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left|W + W'\right| \div 2}{M \times N} \tag{11}$$

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.

For the sake of clarity and simplicity, only one original image blocked by 16×16, F16 is used to analysis in the following discussion.

A. Cropping Attacking

Image cropping is frequently used in real life, which is a lossy operation. Four different cropping attacks are carried out to the watermarked image, respectively. The experimental results are shown in Fig. 6. The watermarked image and extracted watermark from (a) to (d) subjected cutting quarter in center, cutting quarter, cutting half and cutting three quarter, respectively. The proposed algorithm is resistant to a large extent cropping attack, which has wonderful performance in the experiments.



(a) (b) (c) (d)

Figure 6. Watermarked image cutting and extracted watermark after cropping.

(a) (b)

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

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 extracted watermarking images are shown in Fig. 7 after the watermarked image is enlarged or reduced in size.

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 algorithms can not resist against aspect ratio adjustment attack, the 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 watermarks, which have stretched by the same way.

D. Filter and Noise Attacks

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. 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. The embedded watermark can be extracted and detected from the watermarked image of added Pepper-and-Salt noise. It can be observed that extracted watermark is a noisy image, (shown in Fig. 10) which nearly can not be recognizable when adding Pepper-and-Salt noise upon 0.01.

(a) (b)

Figure 8. (a) Watermarked image (height stretched to 2 times) and extracted watermark (b) Watermarked image (width stretched to 2 times) and extracted watermark

(a) (b)

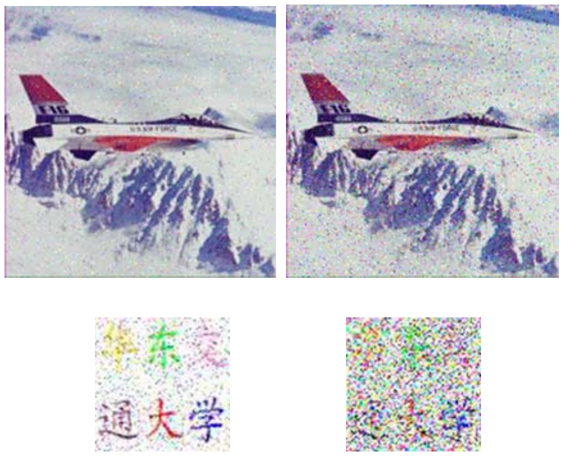
Figure 9. (a) Watermarked image and retrieved watermark (NC=0.8785) under median filtering attack.
(b) Watermarked image and retrieved watermark (NC=0.9757) under Gaussian low-pass filtering attack.

TABLE I
RESULTS OF DIFFERENT QF UNDER JPEG COMPRESSION

QF (%)	100	90	80	70	60
NC	1	0.9996	0.9987	0.9976	0.9961
QF (%)	50	40	30	20	10
NC	0.9879	0.9691	0.9041	0.7602	0.6784

E. Robustness to JPEG Compression

In this experiment, the watermarked images are compressed with different compression factors from 10 to 100 increasing in steps of 10. We show the watermark extracted from JPEG compressed F16 image with various quality factors (QF). Briefly, JPEG quality factor is an indication of the distortion, such that 100% quality factor corresponds to least distortion. Table Ⅰ gives NC values of different QF under JPEG compression. It is variously that the algorithm is strongly resistant to JPEG compression.



(a) (b)

Figure 10. (a)Watermarked image and retrieved watermark (NC=0.8143) under Pepper-and-Salt noise attack (density=0.005).
(b)Watermarked image and retrieved watermark (NC=0.6927) under Pepper-and-Salt noise attack (density=0.01).

TABLE II.
NC RESULT VALUES OF THREE IMAGES UNDER DIFFERENT ATTACKS

Attack type	Waterfall NC			Water NC			Watch NC		
	16×16	32×32	64×64	16×16	32×32	64×64	16×16	32×32	64×64
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	0.9712	1.0000	0.9998	0.9837	0.9989	1.0000	0.9927	0.9984	1.0000
Cutting three quarter	0.9937	0.9999	1.0000	0.9896	0.9979	1.0000	0.9926	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	0.9996	0.9983	0.9983	0.9964	0.9953	0.9942	0.9935	0.9921	0.9961
JPEG QF=30	0.9010	0.8837	0.9032	0.9033	0.9148	0.9101	0.9073	0.9056	0.9205
JPEG QF=20	0.7661	0.7478	0.7675	0.7832	0.7921	0.8001	0.8031	0.7958	0.8015
Median filtering 5×5	0.8811	0.8906	0.8775	0.8784	0.8917	0.8848	0.8927	0.8785	0.8629
Gaussian low pass filtering 5×5	0.9813	0.9821	0.9754	0.9849	0.9778	0.9829	0.9858	0.9779	0.9814
Pepper and Salt noise 0.005	0.8151	0.8139	0.8004	0.8167	0.8202	0.8167	0.8074	0.8207	0.8047
Pepper and Salt noise 0.01	0.7273	0.7118	0.7329	0.7207	0.7027	0.7321	0.7028	0.7172	0.7203

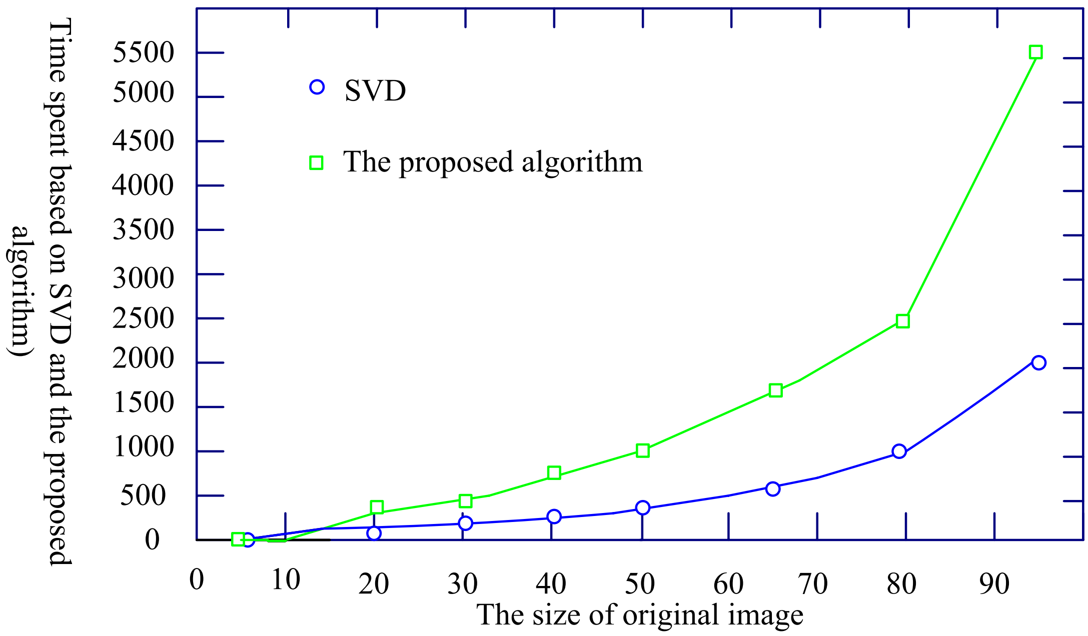


Figure 11. The time comparison between SVD algorithm and the proposed algorithm

TABLE III

NC RESULT VALUES COMPARISON BETWEEN THE PROSOSEDMETHOD AND ZHANG [18] UNDER DIFFERENT ATTACKS

Attacks	parameter	this paper	Zhang[20]
		8×8	8×8
Gauss Low pass Filter	5*5	0.9813	0.9448
	7*7	0.9801	0.9448
Geometric Crop	1/4	0.9999	0.9608
	1/2	1.0000	0.9563
Salt-pepper Noise	0.0005	0.9715	0.9608
	0.0006	0.9682	0.9608
JPEG	QF=30	0.9010	0.8991
	QF=20	0.7661	0.7714

F. Comparing with the Block DCT for Dual Color Images

As mentioned, the method in ref. [18] was a block DCT for dual color images based watermarking algorithm. In which the original watermark image and the original host image in RGB color space are converted to YC_bC_r color space, and the block DCT is implemented on their Y 、 C_b and C_r layer respectively. The watermark sequence is obtained by the operations of spread spectrum and scrambling on the binary sequence, which is embedded into the middle and low frequency coefficients of Y、 C_b and C_r layer of the original host color image. Table Ⅲ gives the NC values comparison between Zhang and the proposed method under the common attacks.

The main idea of SVD is to decompose a rectangular matrix into three simple matrices to multiply. The time complexity is $O(n^3)$, which takes much time for embedding a watermark in a large image. In experiments, we use the same software and hardware, (Operating System Windows XP, CPU Intel Pentium 4, 3.4 GHz processor, PC System Memory 2 GB and Matlab 7.0 simulation platform). Fig.11 shows the time spent in embedding the same watermark into the same original image between SVD algorithm and the proposed algorithm. We can see the Block-SVD method with circulation proposed in this paper has a low computational complexity, and its advantage becomes more conspicuous as the increasing of the size of original image.

V. CONCLUSIONS

In this paper, a color watermark algorithm for color image based on SVD and chaos with circulation is 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 three decomposed watermark components are divided into small watermarks by $b \times b$ and the same components of original image blocked by 16×16, 32×32 and 64×64. Performed SVD on each small watermark block and embedded SVs into one same color Singular Value matrix 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 cropping attacks. The deficiency of the algorithm is consistency between extraction and embedment. The blocks must be partitioned in the same way used in the embedding process. Otherwise, the watermark cannot be correctly detected.

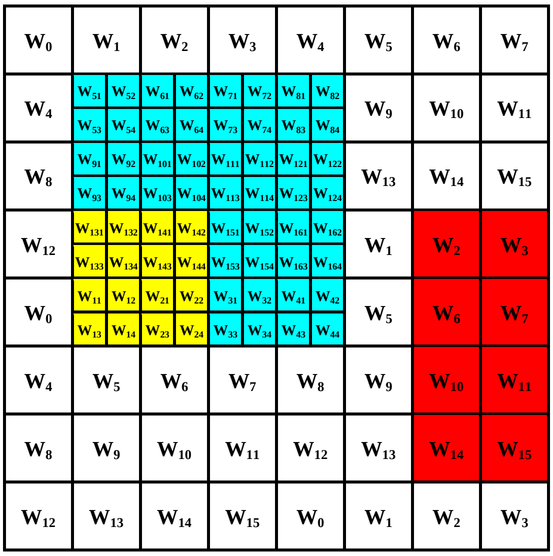


Figure 12. Different partition.

For example, the image to be watermarked is divided into 8×8 blocks and the watermarked image is partitioned into 16×16 blocks before extracted (shown as in Fig. 12). Every embedded watermarking block is partitioned into four pieces when the extraction finished (shown as the yellow region in upper figure). These incomplete fragments of watermark information with no sequence identification number cannot be combined into one recognizable watermarking image.

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