A Blind Multiple Watermarks based on Human Visual Characteristics

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Article Info	ABSTRACT
	Digital watermarking is an alternative solution to prevent unauthorized duplication, distribution and breach of ownership right. This paper proposes a watermarking scheme for multiple watermarks embedding. The embedding of multiple watermarks use a block-based scheme based on human visual characteristics. A threshold is used to determine the watermark values by modifying first column of the orthogonal U matrix obtained from Singular Value Decomposition (SVD). The tradeoff between normalize cross-correlation and imperceptibility of watermarked image from quantization steps was used to achieve an optimal threshold value. The results show that our proposed multiple watermarks scheme exhibit robustness against signal processing attacks. The proposed scheme demonstrates that the watermark recovery from chrominance blue was resistant against different types of attacks.

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1. INTRODUCTION

Nowadays, digital images can easily be duplicated, copied, distributed and modified. Thus, copyright protection method has a growing demand to ensure the content ownership. Digital watermarking has greatly facilitated to protect the copyright, security, editing of digital data and replication of digital data in the last few decades [1]-[3]. In recent year, multiple watermarks concept of single watermark model drew widespread attention for multimedia security. Multiple watermarking models may contain more than a watermark in the host image [4]. For example, in the case of movie production, multiple originators: director, producer and house production are involved, therefore they need multiple ownership watermarks. For digital image photography, photographing editing and producing digital images also require multiple ownership copyrights. Medical images need multiple watermarks for ownership watermark and alteration verification watermark. For collaborative distributions, the product is embedded by multiple watermarks (for different retailers and distributors).

Many researchers presented the hybrid scheme: Discrete Cosine Transform-Singular Value Decomposition (DCT-SVD) watermarking scheme [5]-[8] that can improve the robustness and invisibility of watermarked images. Lai's scheme [6] revealed the relationship of the orthogonal matrix U in the first column matrix of SVD. The scheme showed an improvement of imperceptibility and robustness under signal processing attacks. Therefore, some SVD-based watermarking techniques explored U or V matrices instead of S as presented in Chang *et al.* [9], Chung *et al.* [10], Fan *et al.* [11], Lai *et al.* [6]. These techniques avoid the probability of the false positive problems which may occur when embedding is performed into singular value (S). Though many watermarking techniques have been widely used for copyright protection, only few

methods [11]-[14] have been formulated for multiple watermarking scheme. Multiple watermarking scheme provides more security and robustness [16], [17].

This paper describes a hybrid method using DCT-SVD based on human visual characteristics for multiple watermarks. Referring to [18], red color contributes 65% cones which sensitive to human eyes, green color provides 33% sensitivity and blue color has produces 2% sensitivity. Embedding multiple watermarks on green and blue colors successively can achieve transparency watermarked image. While the watermark can easily be removed when the watermarked image was compressed by JPEG. Luminance and chrominance blue exihibite less sensitivity to human eyes. Therefore, watermark bits are embedded into luminance and chrominance blue components. Embedding of multiple watermarks is performed by examining the relationship of $U_{3,1}$ and $U_{4,1}$ coefficients of SVD. To enhance the security of watermarked images, the two watermarks are scrambled by Arnold chaotic. Finally, the selected blocks are inversed by SVD and DCT to get the watermarked image. The proposed scheme can achieve an improved robustness and imperceptibility of watermarked image.

The related works demonstrate that multiple watermarks are a vital role in multimedia security. This watermarking model can be improved by the hybrid techniques and extra security can be achieved using scrambled watermarks. A new hybrid block-based image watermarking is proposed based on the HVS characteristics and the embedding process is carried out based on modifying first column of orthogonal matrix U of SVD. This scheme attains high robustness against attacks. The highlights and some special features of the proposed scheme are provided as follows:

a. Our scheme proposes multiple watermarks embedding which considers entropy and edge entropy. This paper proposes an optimal threshold for multiple watermarking in luminance and chrominance blue. Our scheme produces minimum distortion in the visual watermarked image.
b. Multiple watermarks embedding are performed by examining the first column of U matrix. Watermark embedding on U matrix of luminance and chrominance blue can improve the robustness and invisibility of multiple watermarks.
c. Confidentially of watermark image is an important information, it should be extracted by authorized users. To improve the security level, multiple watermarks are scrambled before they are embedded into luminance and chrominance blue which can provide extra security in the watermarked image.
d. By finding optimal thresholds for each image component, the quality of the watermarked image produces high image quality and the recovered watermark resistants against different types of attack.

2.   RESEARCH METHOD
2.1. Arnold scrambling

Watermark images are scrambled by Arnold chaotic map to increase the security of multiple watermarking. Scrambled watermarks cannot be recovered without a secret key even attackers successfully extract the watermark from luminance and chrominance blue components of the watermarked image. Arnold scrambling transformation is defined by [19]:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} \bmod N \tag{1}$$

where $\begin{pmatrix} x' \\ y' \end{pmatrix}$ represents vector position after shifting, $\begin{pmatrix} x \\ y \end{pmatrix}$ represents original vector position before shifting

and *mod* denotes the modulus operation after division with N. The parameter N represents the period of Arnold scrambling. In this experiment, the number of iteration order N is used as a secret key for scrambling transformation. In order to inverse the watermark image, the inverse Arnold transformation can be defined by:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 2 & -1 \\ -1 & 1 \end{pmatrix}\begin{pmatrix} x' \\ y' \end{pmatrix} \bmod N \tag{2}$$

2.2. Human visual characteristics

Human visual characteristics less sensitive against redundancy of image information. It can be described through entropy to determine most redundant image information. Entropy was exploited to select significant embedding region. Entropy are applied to determine embedding locations for multiple watermarks

image. Embedding certain amount of watermark bits in the luminance and chrominance must be invisible to human eyes. The entropy was used to measure the spatial correlation of neighbor pixels. Entropy of an *N*-state is defined by [20]:

$$E = -\sum_{i=1}^{N} p_i \log_2(p_i) \tag{3}$$

Image edge is an important information of image characteristics. Edge entropy of an image block is considered for embedding regions. Edge entropy is given as follows:

$$E_{edge} = -\sum_{i=1}^{N} p_i \exp^{1-p_i} \tag{4}$$

where p_i denotes the occurrence probability of *i*-th pixel with $0 \le p_i \le 1$ and $1 - p_i$ represents the uncertainty or ignorance of the pixel value. The values obtained from combination between entropy and edge entropy are sorted in ascending order and the lowest value are choosen as embedding regions.

2.3. DCT

A true-color host image is transformed into YCbCr color space. Each component (luminance and chrominance blue) is divided into small blocks, then each block is computed by modified entropy. Selected blocks are transformed by two-dimensional DCT to produce the frequency image signals. The two-dimensional DCT matrix *B* of an input image *A* is computed by [21]:

$$B_{pq} = \alpha_p \beta_q \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} A_{mn} \cos \frac{\pi(2m+1)p}{2M} \cos \frac{\pi(2n+1)q}{2N}, \tag{5}$$

for $p = 0, 1, 2, \ldots, M-1$ and $q = 0, 1, 2, \ldots, N-1$ where

$$\alpha_p = \begin{cases} \dfrac{1}{\sqrt{M}}, & for \quad p = 0 \\ \sqrt{\dfrac{2}{M}}, & for \quad p > 0 \end{cases} \qquad \beta_q = \begin{cases} \dfrac{1}{\sqrt{N}}, & for \quad q = 0 \\ \sqrt{\dfrac{2}{N}}, & for \quad q > 0 \end{cases} \tag{6}$$

The inverse of two-dimensional DCT is calculated using

$$A_{pq} = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \alpha_p \beta_q B_{mn} \cos \frac{\pi(2m+1)p}{2M} \cos \frac{\pi(2n+1)q}{2N}, \tag{7}$$

The DCT coefficients are then transformed by SVD which is described in the next sub-section.

2.4. SVD

The SVD factorizes a real or complex matrix into three matrices which are *U*, *S* and *V* matrix. SVD of *A* can be presented as follows [22]:

$$A = USV^T \tag{8}$$

Where *U* is orthonormal eigenvectors of AA^T, *S* is a diagonal matrix containing the square of the eigenvalues *A* in descending order and *V* is orthonormal vectors of A^TA. Embedding is performed in the first column of the orthogonal matrix *U* by examining $U_{3,1}$ and $U_{4,1}$ using some rules. The rules are used to embed and extract multiple watermarks in the DCT-SVD domain. The rules are described in the proposed watermarking embedding and extraction algorithms in the next section.

2.5. Imperceptibility measurement

This section describes the metrics to evaluate the proposed watermarking scheme. In order to demonstrate the performance of the proposed scheme, the watermarked imperceptibility is evaluated by structural similarity (SSIM) index. SSIM is computed by:

$$SSIM(x,y) = \left[l(x,y)\right]^{\alpha} \cdot \left[c(x,y)\right]^{\beta} \cdot \left[s(x,y)\right]^{\gamma} \tag{9}$$

where $\alpha > 0$, $\beta > 0$, $\gamma > 0$, are parameters which can be adjusted to signify their relative importance.

2.6. Robustness measurement

Robustness of watermark extraction is measured by Normalized Cross-Correlation (NC) and Bit Error Rate (BER). NC and BER are given as [23]-[25]:

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j).W^{*}(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)^{2}\sum_{i=1}^{M}\sum_{j=1}^{N} W^{*}(i,j)^{2}}} \tag{10}$$

$$BER = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j) \oplus W^{*}(i,j)}{M \times N} \tag{11}$$

where $\oplus$ denotes the exclusive OR operation. M and N represent rows and columns size of the watermark image, $W^{*}(i,j)$ is the extracted watermark and the $W(i,j)$ is the original watermark.

3. PROPOSED SCHEME
3.1. Watermark insertion

Watermark insertion process is divided into ten steps. The proposed multiple watermarks scheme is described in Algorithm 1.

Algorithm 1: Watermark Insertion

Input: Host image; watermark; threshold (T)	
Step 1:	The cover color image is converted to YCbCr color channels. Embedding multiple watermarks is performed in Luminance (Y) and Chrominance-Blue (Cb).
Step 2:	Luminance and chrominance blue are divided by 8×8 pixels.
Step 3:	Calculate entropy values for each block.
Step 4:	Select blocks based on entropy values and save the x and y coordinates
Step 5:	Both binary watermarks are scrambled by Arnold chaotic.
Step 6:	Apply DCT for each selected blocks.
Step 7:	Perform SVD based on block-based DCT coefficients for watermark embedding.
Step 8:	For each watermark bit, embed watermark according to the rules as follows:
	Rule 1: if the number of bits are less than maximum watermark bits, calculate the average $U_{3,1}$ and $U_{4,1}$ coefficients and save it to m.
	Rule 2: if the binary watermark equal to 1 and $U_{3,1}$ coefficient is less than $U_{4,1}$ coefficient, modify the coefficients by: $U_{3,1}=m+T/2$; $U_{4,1}=m-T/2$.
	Rule 3: if the binary watermark bit equal to 0 and $U_{3,1}$ coefficient is less than $U_{4,1}$ coefficient, modify the coefficients by: $U_{3,1}=m-T/2$; $U_{4,1}=m+T/2$.
Step 9:	Perform the inverse SVD, then applying the inverse DCT on each selected block.
Step 10:	Merging all YCbCr components and convert YCbCr to RGB color image to obtain the watermarked image.
Output: Watermarked image containing a watermark	

3.2. Watermark extraction

Step-by-steps to extract multiple watermarks are divided into sevent steps as described in Algorithm 2.

Algorithm 2: Watermark Extraction

Input: Watermarked image	
Step 1:	A watermarked color image is converted to YCbCr color channels. Extraction multiple watermarks is performed in Luminance (Y) and Chrominance-Blue (Cb)
Step 2:	Selected block coordinates are used to find the location of embedded multiple watermarks
Step 3:	Apply DCT for each selected blocks.
Step 4:	Perform SVD on DCT selected block coefficients for extraction purpose in the first column orthogonal U matrix.
Step 5:	For each bit of recovered binary watermark is described as follows:
	Rule 1: if the number of recovered watermark bits are less than watermark size, calculate the different between $U_{3,1}$ and $U_{4,1}$ coefficients
	Rule 2: if the different value of $U_{3,1}$ and $U_{4,1}$ coefficients is greater than 0, then binary recovered watermark bit =1.
	Rule 3: if the different value of $U_{3,1}$ and $U_{4,1}$ coefficients is lesser than 0, then binary recovered watermark bit =0.
Step 6:	Perform Step 3 to Step 5 for both luminance and chrominance-blue channels until the length of the watermark.
Step 7:	Apply inverse Arnold chaotic for both binary watermarks
Output: Watermark recoveries	

4.   EXPERIMENTAL RESULTS

The proposed multiple watermarking scheme is employed on five true color images with 512×512 pixels as shown in Figure 1. The original true color images are taken from CVG-UGR database [26].
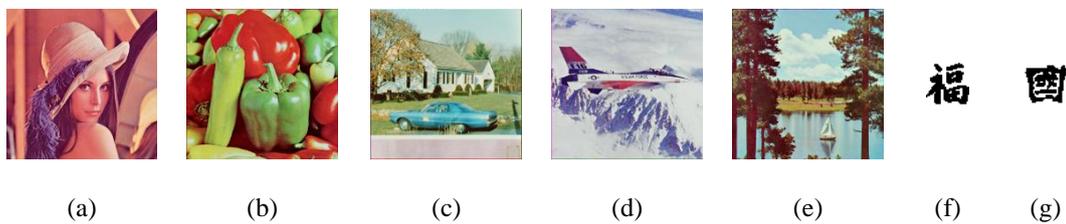

(a)   (b)   (c)   (d)   (e)   (f)   (g)

Figure 1. Host images: (a) Lena, (b) pepper, (c) car, (d) airplane, (e) sailboat (f) first watermark (g) second watermark

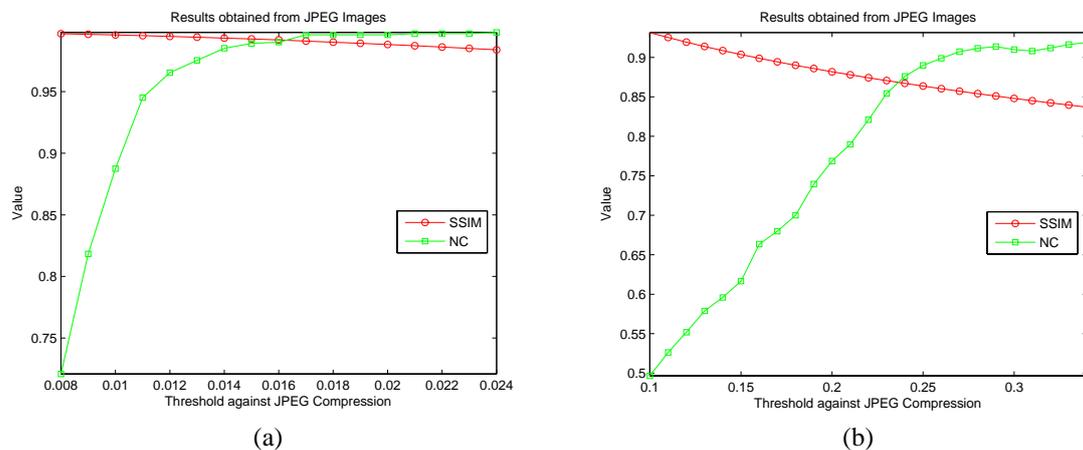(a)   (b)

Figure 2. An optimal threshold for (a) luminance and (b) chrominance blue

The number of selected blocks for luminance and chrominance blue is 1024, it equal to the watermark size with 32×32 pixels. Using the experiment, we find a threshold as an optimal trade-off between transparency and robustness against JPEG compression for the proposed scheme. JPEG compression is the most popular standard image compression techniques and it has been widely implemented on most digital cameras [27]-[37]. The experimental results have revealed the optimal thresholds as about 0.016 and 0.24 for luminance and chrominance, respectively as shown in Figure 2. The multiple watermark insertion and extraction process are shown in Figure 3 and Figure 4.
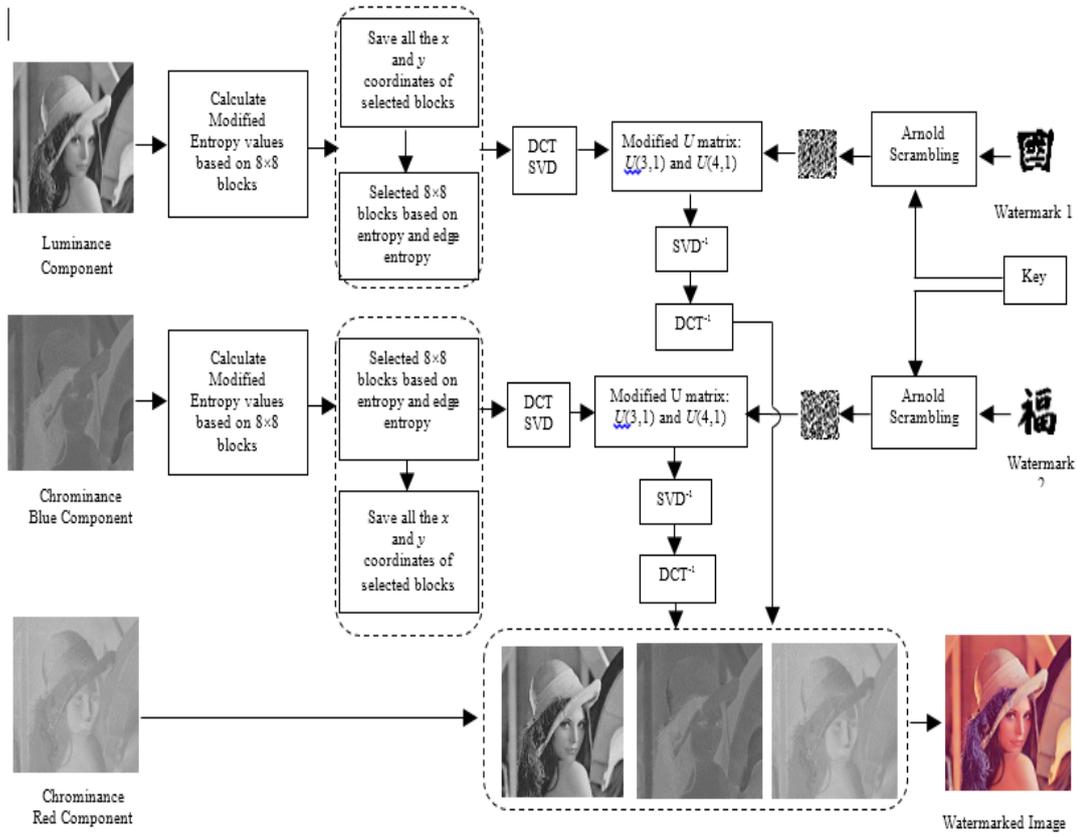
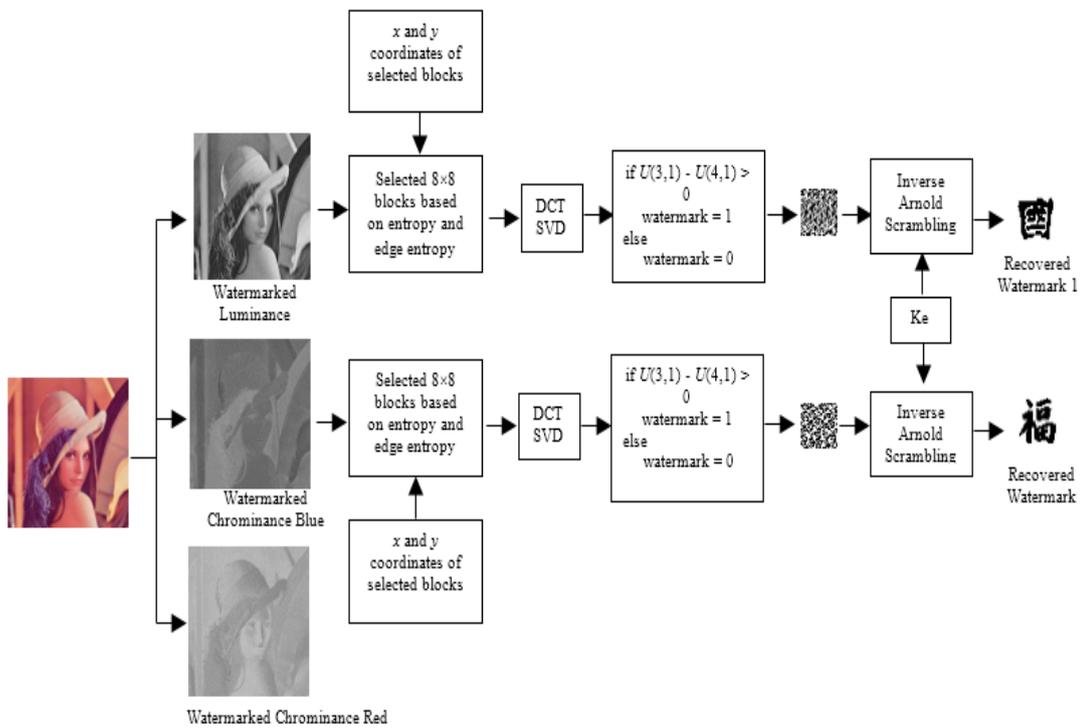Figure 3. Embedding block diagram

Figure 4. Extraction block diagram

In this experiment, the proposed multiple watermarks prove the robustness against signal processing attacks especially for embedding in chrominance blue. The embedding in the chrominance blue channel can provide less distortion and it provides higher robustness than embedding in the luminance component. Figure 5 shows the recovered multiple watermarks under the different types of attack. Table 1 and Table 2 show the imperceptibility and robustness of watermarked image from Lena image.
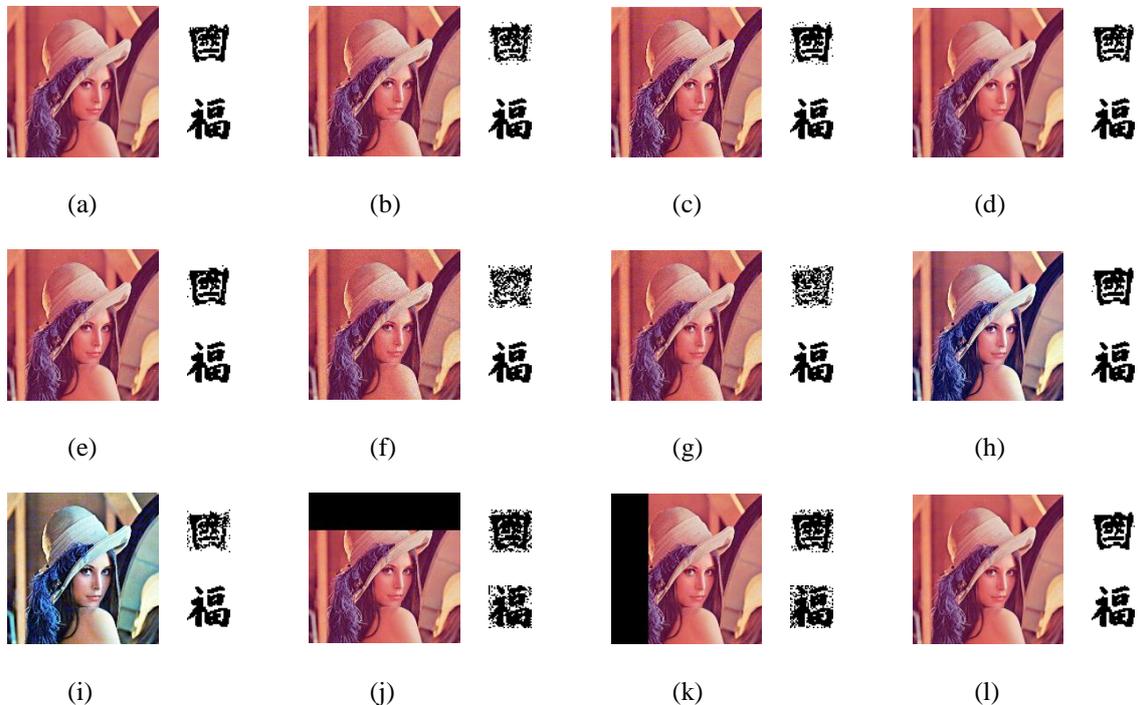

Figure 5. Results under different types of attack and the corresponding recovered watermark using
(a) gaussian low pass filter [33], (b) gaussian noise 0.001, (c) sharpening, (d) median filter (3×3), (e) pepper and salt noise 0.1%, (f) speckle noise 0.01, (g) poisson noise, (h) adjust, (i) histogram equalization attack
(j) cropping rows off 25%, (k) cropping columns off 25%, (l) scaling 0.5

Table 1. NC Values for Lena Image under different Geometrical Attacks

Attack	SSIM	Watermark 1		Watermark 2	
		NC	BER	NC	BER
Cropping rows off 25%	0.6605	0.8100	0.1699	0.8393	0.1475
Cropping rows off 50%	0.4364	0.6427	0.2900	0.6471	0.2900
Cropping columns off 25%	0.6547	0.8824	0.1094	0.8252	0.1592
Cropping columns off 50%	0.4176	0.8293	0.1543	0.7363	0.2285
Rotation 2˚	0.4905	0.5542	0.4756	0.4635	0.5078
Rotation 45˚	0.2004	0.5069	0.4922	0.4203	0.5186
Translate attack (10, 10)	0.2773	0.5292	0.5264	0.4650	0.5195
Translate attack (10, 20)	0.2680	0.4063	0.4980	0.4449	0.5146
Scaling 0.5	0.8845	0.9970	0.0029	1	0
Scaling 0.25	0.8857	0.6520	0.3398	0.9980	0.0020

Table 2. NC Values for Lena Image under different Signal Processing Attacks

Attack	SSIM	Watermark 1		Watermark 2	
		NC	BER	NC	BER
Gaussian Low Pass Filter [3 3]	0.8857	0.9780	0.0225	1	0
Gaussian Low Pass Filter [5 5]	0.8881	0.9609	0.0410	1	0
Gaussian Noise 0.001	0.8039	0.9068	0.0918	1	0
Gaussian Noise 0.005	0.6512	0.7248	0.2842	1	0
Sharpening	0.7930	0.9535	0.0449	1	0
Median Filter [3 3]	0.8835	0.9722	0.0283	1	0
Median Filter [5 5]	0.9031	0.7834	0.2813	0.9923	0.0078
Pepper and Salt Noise 0.1%	0.8548	0.9831	0.0166	1	0

Attack	SSIM	Watermark 1		Watermark 2	
		NC	BER	NC	BER
Pepper and Salt Noise 1%	0.7386	0.8438	0.1533	1	0
Speckle Noise 0.01	0.7079	0.7774	0.2197	1	0
Poisson Noise	0.7466	0.8172	0.1846	1	0
Adjust	0.7925	0.9950	0.0049	1	0
Histogram Equalization Attack	0.6726	0.9030	0.0957	1	0
JPEG with Q=40	0.8824	0.5874	0.3857	0.7377	0.2559
JPEG with Q=50	0.8684	0.8203	0.1729	0.8738	0.1270
JPEG with Q=60	0.8653	0.9527	0.0469	0.9195	0.0811
JPEG with Q=70	0.8680	0.9970	0.0029	0.9740	0.0264

Figure 6 shows bit error rate of the proposed scheme against JPEG and JPEG2000 compression with different types of compression level. It can be noticed that watermark insertion in chrominance blue is more resistants against JPEG2000 than watermark insertion in luminance.
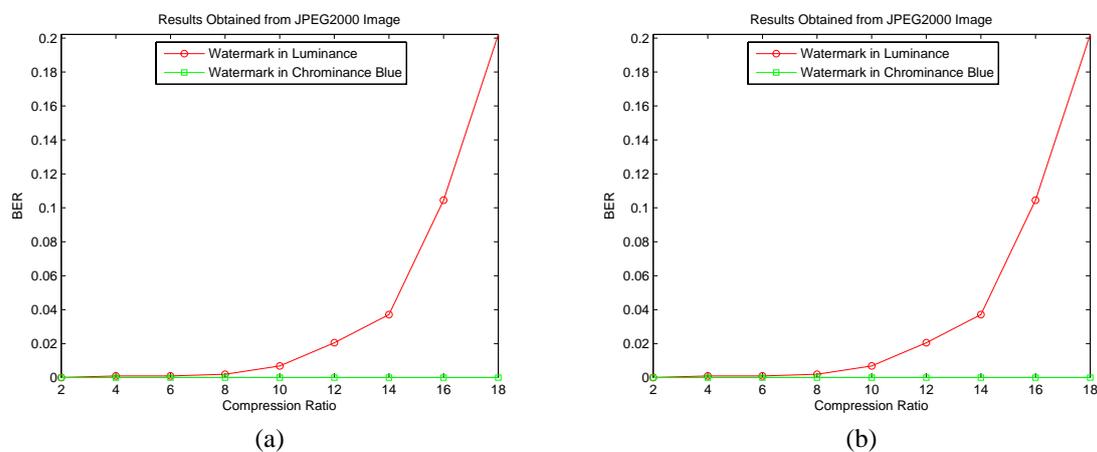

(a)   (b)

Figure 6. BER values of the proposed scheme against JPEG and JPEG2000 compression

5.   CONCLUSION

This paper proposes block-based multiple watermarking scheme based on human visual characteristics. This experiment demonstrated the multiple watermarks insertion into host images by examining $U_{3,1}$ and $U_{4,1}$ of the orthogonal matrix. The proposed scheme provides robustness and resistance against signal processing attacks. The two scrambled watermarks provides extra security and difficult to be identified. The distributed watermarks embedding based on human visual characteristics can achieve high imperceptibility of watermarked image. Furthermore, the embedding scheme for luminance and chrominance blue pairs effectively provides resistance to altered signal processing attacks like JPEG, image noise, image filter, sharpening, and geometric attacks like scaling, translation, cropping. The optimal threshold for multiple watermarks is able to achieve optimal robustness and imperceptibility. The results have proven that our proposed scheme holds excellent robustness and imperceptibility for multiple watermarks.

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