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MULTIPLE WATERMARKING TECHNIQUE BASED ON RDWT-SVD AND HUMAN VISUAL CHARACTERISTICS

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ABSTRACT

With the increasing multimedia technology, digital watermarking technique is needed for copyright protection. The multiple watermarking technique is required for embedding more than one watermarks. A major challenge needs to be solved specially to recover multiple watermarks that may be destroyed due to JPEG compression. This paper proposed multiple embedding techniques for watermarks based on RDWT-SVD and human visual characteristics. The proposed scheme examines $U_{(2,1)}$ and $U_{(3,1)}$ components of RDWT-SVD. Our scheme uses Arnold transform to scramble the watermarks before embedding watermarks into the host image. The proposed scheme is tested under several attacks such as image compression, geometrical and image processing attacks. The experimental results show that our scheme can achieve a higher robustness for both recovered watermarks than the existing technique. Our scheme produces high robustness with the normalized-cross-correlation about 0.99 under noise additions.

Keywords: *Redundant Wavelet Transform, Singular Value Decomposition, Arnold Transform, HVS Characteristic, Multiple Watermarking*

1. INTRODUCTION

The evolution of digital technologies and the internet have led to the production and distribution of digital media. Digital media such as audio, video, image and text can be easily modified by unauthorized persons. It is important to protect the ownership of the digital media against unauthorized copied and re-distributed. Digital watermarking is one of solutions to protect the intellectual copyright [1][2]. The essential requirements needed in watermarking are robustness, imperceptibility, security and capacity [3]-[5]. The robustness of the recovered watermark should be resistant against image processing and geometrical attacks. The imperceptibility of the host image must be minimally modified when the watermark was embedded into the host image.

The multiple watermarks concept drew attention to multi-media security [6]. The multiple watermarks scheme may contain a combination of two or more watermarks embedded into host image [7]. Multiple watermarks embedding may not resist against standard JPEG compression. The embedding of the second watermarks may not robust against JPEG compression due to the quantization process. JPEG quantization reduces large redundancy on the chrominance channels by assigning large values in JPEG quantization chrominance. In order to improve robustness and imperceptibility, researchers suggested to use hybrid techniques for developing the watermarking scheme [8]-[12].

This paper proposes a hybrid method using redundant discrete wavelet transform (RDWT) and singular value decomposition (SVD). Multiple watermarks are embedded in red and blue color channels. The smallest value of the modified entropy is used to select the embedding locations for multiple watermarks. RDWT is applied to each selected block to decompose low-low sub-band (LL), high-low sub-band (HL), low-high sub-band (LH) and high-high sub-band (HH). Next, SVD is applied to LL sub-band to obtain *U*, *S* and *V* matrices. First and second watermarks are embedded in the first column of *U* matrices by modifying $U_{(2,1)}$ and $U_{(3,1)}$ on the red and blue colors respectively. To enhance the security, the multiple watermarks are scrambled by Arnold transform. The proposed scheme can provide high robustness for both embedded multiple watermarks under JPEG compression.

This paper is organized as follows. Section 2 describes the related work of the multiple watermarking techniques. Section 3 discusses the preliminaries of the proposed multiple image

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watermarking. Section 4 presents the proposed watermark insertion and extraction. Section 5 shows the experimental results and finally concludes in Section 6.

2. RELATED WORK

In the last decades, researchers formulated watermarking scheme based on a hybrid scheme. Ernawan's [6] presented a hybrid method using DCT-SVD based on human visual characteristics for multiple watermarks. Multiple watermarks are embedded in the luminance and chrominance blue channels. This scheme used 8×8 non-overlapping blocks for selecting embedded regions. The experimental results from Ernawan's scheme presented a good robustness for both extracted watermarks against image processing attacks.

Makbol and Khoo [13] presented a watermarking scheme based on the RDWT- SVD to improve the robustness and imperceptibility of the watermarked image. Makbol and Khoo's scheme embedded the watermark into the singular values of RDWT-SVD. Their schemes can achieve high imperceptibility of the watermarked image. Gaur and Srivastava [14] presented a dual watermarking approach using RDWT-SVD and Arnold transform to improve the robustness and security. Gaur and Srivastava's scheme used two watermarks, the second watermark is embedded into the prime watermark. Thus, the prime watermark is inserted into the hos image using RDWT-SVD. The prime watermark is embedded in the singular value decomposition using a scaling factor. Gaur's scheme shows that it produces high robustness and provides large embedding capacity. While, watermark embedding on the singular value decomposition may lead to produce false-positive problem.

Embedding multiple watermarks into the luminance and chrominance as stated in [6] may not achieve an optimal robustness especially for chrominance channel. Embedding watermark in chrominance which contains less information that gives significant effect in the robustness of embedded watermark. The proposed scheme will embed the watermarks into red and blue colors. The selecting red and blue color due to the human visual system is most sensitive to green color. The embedding regions with non-overlapping block of 4x4 pixels is proposed to achieve better quality of image reconstruction. The used RDWT-SVD can improve the robustness instead of DCT-SVD in image watermarking.

3. PRELIMINERIES

3.1 RDWT

RDWT is a technique to overcome the shift variance property that occurs in the presence of down a sampler of DWT [13]. RDWT is a shift invariance where it obtained by eliminating down sampling operator for the usual implementation of DWT [3]. RDWT analysis and synthesis are given by:

- RDWT *analysis*

$$c_j[k]=\left(c_{j+1}[k]*h_j[-k]\right) \tag{1}$$

$$d_j[k]=\left(c_{j+1}[k]*g_j[-k]\right) \tag{2}$$

- *RDWT Synthesis*

$$c_{j+1}[k]=\frac{1}{2}\left(c_j[k]*h_j[k]+d_j[k]*g_j[k]\right) \tag{3}$$

where $g[-k]$ and $h[-k]$ denotes as high pass and low pass analysis filters, $g[k]$ and $h[k]$ represents high pass and low pass synthesis filter, c_j and d_j denotes low band and high band coefficients at level j.

3.2 SVD

SVD is a numeric tool for decomposing into three matrices, U, S and V matrices [15][16]. The matrix of U and V represent the geometric information, whereas S matrix specify the intensity data of the image. SVD is widely used in image watermarking applications [17]. SVD of A is given by:

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

$$A=\begin{bmatrix} u_{1,1} & u_{1,2} & \cdots & u_{1,n} \\ u_{2,1} & u_{2,2} & \cdots & u_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n,1} & u_{n,2} & \cdots & u_{n,n} \end{bmatrix}\begin{bmatrix} \sigma_{1,1} & 0 & 0 & 0 \\ 0 & \sigma_{2,2} & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \sigma_{n,n} \end{bmatrix}\begin{bmatrix} v_{1,1} & v_{2,1} & \cdots & v_{1,n} \\ v_{2,1} & v_{2,2} & \cdots & v_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n,1} & v_{n,2} & \cdots & v_{n,n} \end{bmatrix}^T \tag{5}$$

where U and V are left and right singular vectors S is a diagonal matrix of singular values arranged in decreasing order; and U and V are the orthonormal matrices.

3.3 Arnold Transform

Arnold transform is widely used to provide additional security image watermarking [12]. Arnold transform performs shifting pixel coordinates to change pixel positions [18]. For the scrambling transformation of the watermarks, iteration order N is used as a secret key. Arnold transform is defined by:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \bmod N \quad (6)$$

where $\begin{pmatrix} x' \\ y' \end{pmatrix}$ are coordinates after shifting, $\begin{pmatrix} x \\ y \end{pmatrix}$ are the original coordinates and *mod* is the modulus with the divisor of *N*. The watermark is recovered using inverse Arnold transform using a same secret key. The inverse Arnold transform is defined as follows:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix} \bmod N \quad (7)$$

3.4 Human Visual Characteristics

The human visual characteristics can be utilized by using entropy and edge entropy. Entropy is used to measure the image information which has redundant information. This paper applies entropy and edge entropy to determine the embedding location. Entropy and edge entropy values may indicate an area with less sensitive to human visual systems and it is suitable for watermarks embedding [19][20]. The modified entropy of HVS characteristics can be defined by average of entropy and edge entropy. Modified entropy HVS is given by:

$$E_{HVS} = \sum_{i=1}^{N} \left(p_i \log_2 (p_i) - p_i e^{1-p_i} \right) / 2 \quad (8)$$

4. PROPOSED SCHEME

This paper proposed thresholds for embedding multiple watermarks for red and blue colors with the human visual characteristics. These thresholds are shown in Figures 1 and 2.

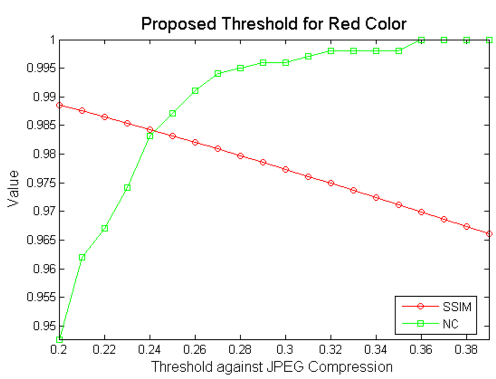

Figure 1: Proposed Threshold of RDWT-SVD for Red Color

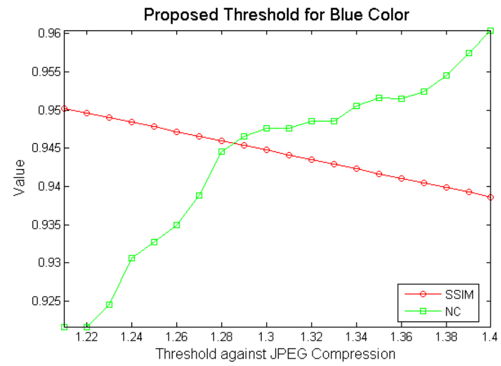

Figure 2: Proposed Threshold of RDWT-SVD for Blue Color

The proposed thresholds are obtained from incrementing a threshold one at a time by considering the balance between robustness and imperceptibility. The thresholds are evaluated by the NC and SSIM against JPEG quantization steps. According to Figures 1 and 2, the proposed threshold value for red color is about 0.24 and blue color is about 1.28.

4.1 Embedding Watermark

The watermark embedding process is divided into few steps. The watermark embedding algorithm is elaborated in details as shown in Algorithm 1. The proposed multiple watermark insertion is illustrated in Figure 3.

Algorithm 1: Embedding Watermark

Input: Color image, Two binary watermarks

- Step 1: A color image is divided into 4×4 pixels. Red and blue colors are selected for embedding multiple watermarks.
- Step 2 Calculate modified entropy values for each block of 4×4 pixels.
- Step 3: Each block that has lowest modified entropy are selected and the coordinates of *x* and *y* are saved into a database.
- Step 4: Both binary watermarks are scrambled using Arnold Transform.
- Step 5: Apply RDWT for each selected block.
- Step 6: Perform SVD on LL sub-band of each selected block.

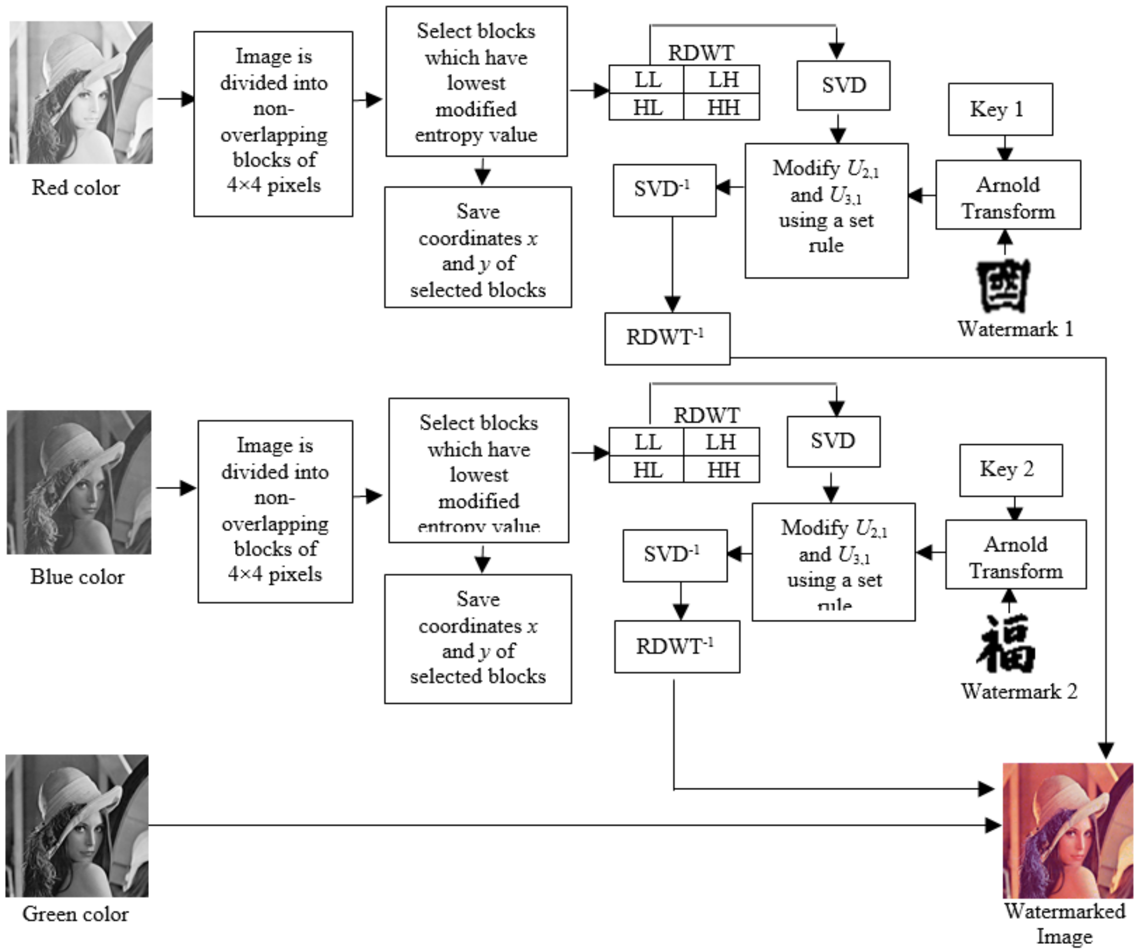

Figure 3: Embedding Multiple Watermark

Step 7: For each watermark bit is embedded by following the rules:

Rule 1: Calculate the average (m) of $U_{(2,1)}$ and $U_{(3,1)}$

Rule 2: If the binary watermark equal to 1, the modification is given by:

$$U_{(2,1)} = x \cdot m + \alpha/2 \text{, where} \begin{cases} x = 1, U_{(2,1)} > 0 \\ x = -1, U_{(2,1)} > 0 \end{cases}$$

$$U_{(3,1)} = x \cdot m - \alpha/2 \text{, where} \begin{cases} x = 1, U_{(3,1)} > 0 \\ x = -1, U_{(3,1)} > 0 \end{cases}$$

Rule 3: If the binary watermark equal to 0, the modification is given by:

$$U_{(2,1)} = x \cdot m + \alpha/2 \text{, where} \begin{cases} x = 1, U_{(2,1)} > 0 \\ x = -1, U_{(2,1)} > 0 \end{cases}$$

$$U_{(3,1)} = x \cdot m - \alpha/2 \text{, where} \begin{cases} x = 1, U_{(3,1)} > 0 \\ x = -1, U_{(3,1)} > 0 \end{cases}$$

Step 8: Apply inverse SVD on each selected block.

Step 9 Implement inverse RDWT on each selected block.

Step 10: Merge all the RGB components to obtain the watermarked image.

Output: Watermarked image

4.2 Extracting Watermark

The watermark extraction process is divided into few steps. The watermark extraction is discussed in Algorithm 2. The proposed multiple watermark extraction is illustrated in Figure 4.

Algorithm 2: Watermark Extraction

Input: Watermarked image, coordinates of x and y

Step 1: Select red (R) and blue (B) colors for extracting watermark.

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Step 2: Coordinates of x and y are used to extract the multiple watermark. The selected region of watermarked image is divided into non-overlapping of 4×4 pixels.

Step 3: Apply RDWT for each selected block.

Step 4: Perform SVD on LL sub-band of each selected block.

Step 5: The binary watermark is extracted using the rules as follows:

Rule 1: if $U_{(2,1)} - U_{(3,1)} > 0$, watermark bit = 1.

Rule 2: if $U_{(2,,1)} - U_{(3,1)} < 0$, watermark bit = 0.

Step 6: Apply inverse Arnold transform for both extracted binary watermark 1 and watermark 2 from red and blue colors respectively.

Output: Extracted watermark 1 and watermark 2

The proposed watermarking technique needs to undergo the evaluation in order to measure the watermarking performance. Two types of evaluations are given as follows in terms of imperceptibility and robustness.

4.3 Imperceptibility Performance

Imperceptibility of the watermarked image is one of the parameters for measuring invisibility of embedded watermark. Structural similarity index (SSIM) is used to measure the similarity of the watermarked image and the original image [11]. If the SSIM value is 1, it means that the quality of the watermarked image equal to the original image or no distortion. SSIM is defined by:

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

where α>0, β>0, γ>0, are parameters which can be adjusted to signify their relative importance. A detailed description can be found in [21]. Absolute Reconstruction Error (ARE) is used to measure the distortion of the watermarked image. ARE can be

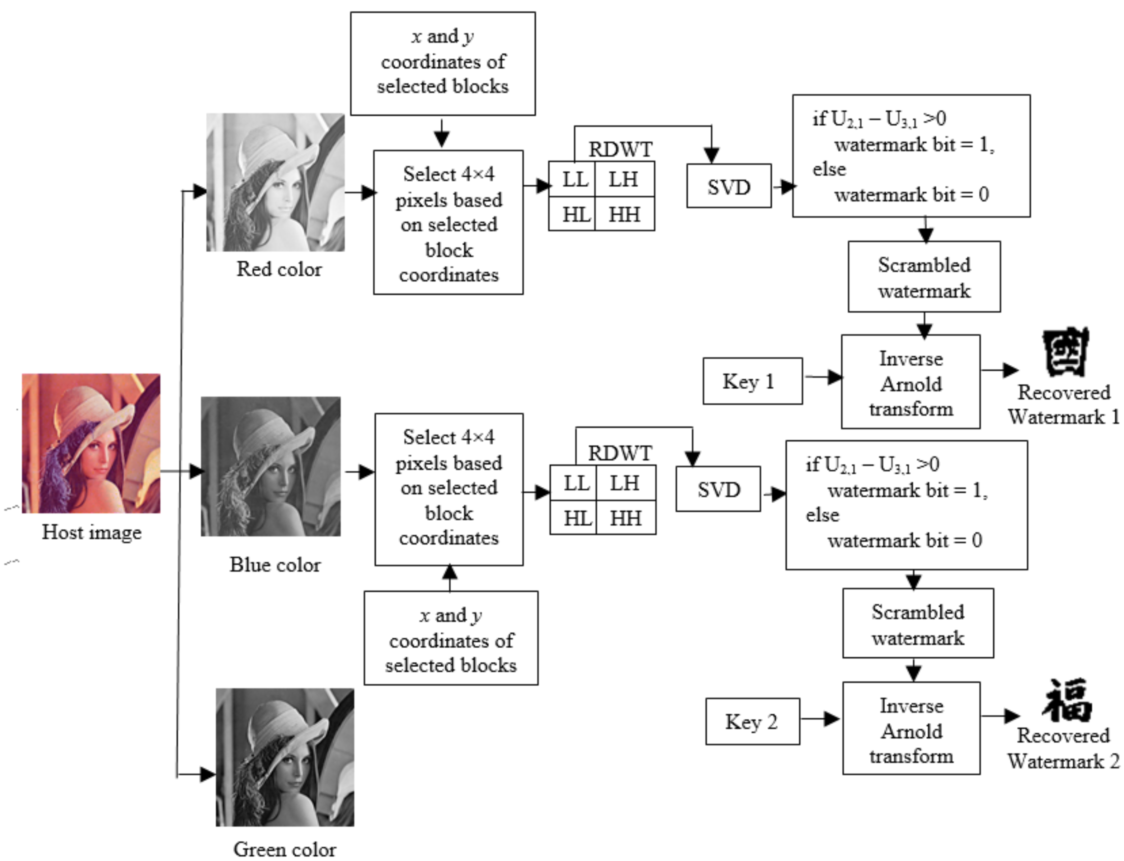

Figure 4: Extracting Multiple Watermark

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defined by:

$$ARE = \frac{1}{MNR}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\sum_{k=0}^{2}\left|g(i,j,k) - f(i,j,k)\right| \quad (10)$$

where M, N represents the row and column size of the host image. R denote the number of color channels, g is the watermarked image and f is the host image. ARE value is representing the distortion on the watermarked image, the smaller ARE value means less errors of watermarked image, it means high imperceptibility. The large ARE value means the embedded watermarks may produce distortion on the watermarked image.

4.4 Robustness Performance

Robustness evaluation is needed to measure the resistance of the extracted watermark after watermarked modification. Image watermarking technique must resist against image processing attacks, e.g. filtering, noise addition, compression and geometrical attacks, e.g. scaling, translation and cropping. The robustness of extracting watermark can be measured by Normalize Cross-correlation (NC) and Bit Error Rate (BER). NC and BER are defined by [22][23]:

$$NC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j).W^*(i,j)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j)^2 \sum_{i=1}^{M}\sum_{j=1}^{N} W^*(i,j)^2}} \quad (11)$$

$$BER = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} W(i,j) \oplus W^*(i,j)}{M \times N} \quad (12)$$

where M and N represent row and column sizes of the watermark image, $W(i,j)$ is the original watermark image, $W^*(i,j)$ is the extracted watermark image and $\oplus$ indicates the OR operation.

5. PROPOSED SCHEME

The watermarking experiments are conducted using MATLAB 2014a. The experiments use five color images with size of 512×512 pixels, namely "Lena", "Pepper", "Baboon", "Airplane" and "sailboat" as shown in Figure 5. Two binary watermarks with size of 32×32 pixels are embedded into red and blue colors respectively.

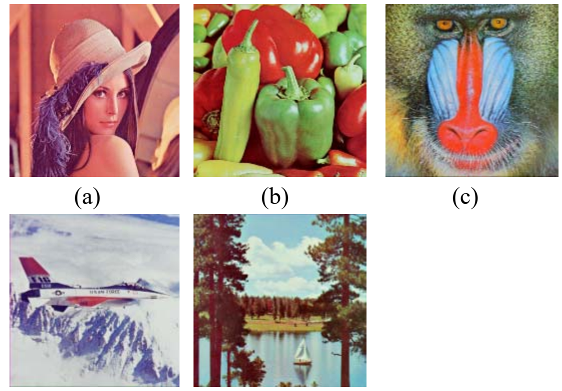

Figure 5: (a) Lena, (b) Pepper, (c) Baboon, (d) Airplane, (e) Sailboat

Figure 6: (a) Watermark 1, (b) Scrambled Watermark, (c) Watermark 2, (d) Scrambled Watermark 2

Two binary watermarks and its scrambled watermarks are shown in Figure 6. The imperceptibility results of the proposed watermarking technique are shown in Table 1.

Table 1: Imperceptibility Comparison Between Ernawan's scheme and the Proposed Scheme

Image	Ernawan's scheme [6]		Proposed scheme	
	ARE	*SSIM*	*ARE*	*SSIM*
Lena	1.8774	0.8996	**1.3075**	**0.9767**
Pepper	0.9957	0.9482	**0.4268**	**0.9948**
Baboon	2.7161	0.9326	**2.3919**	**0.9720**
Airplane	3.8471	0.8459	**2.3559**	**0.9575**
Sailboat	3.6957	0.8849	**2.2774**	**0.9595**

Table 1 shows the comparison between Ernawan's scheme [6] and the proposed multiple watermarks in terms of ARE and SSIM values. The proposed scheme produces higher SSIM values than other scheme, and it has minimum reconstruction errors. The result shows that our scheme outperforms existing schemes by demonstrating less distortion and higher imperceptibility of the watermarked images.

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Table 2: Comparison of NC values between Ernawan's scheme and our proposed scheme under Signal Processing Attacks

Type of Attacks	Watermark 1				Watermark 2			
	Ernawan [6]		Proposed scheme		Ernawan [6]		Proposed scheme	
	NC	BER	NC	BER	NC	BER	NC	BER
Gaussian Lowpass Filter [3,1]	**0.9780**	**0.0225**	0.9489	0.0547	1	0	**1**	**0**
Gaussian Lowpass Filter [5,1]	**0.9609**	**0.0410**	0.9489	0.0547	**1**	**0**	0.9990	0.0010
Gaussian Noise 0.001	0.9019	0.0967	**1**	**0**	1	0	**1**	**0**
Gaussian Noise 0.005	0.7346	0.2715	**1**	**0**	1	0	**1**	**0**
Sharpening	0.9535	0.0449	**1**	**0**	1	0	**1**	**0**
Median [3,3]	**0.9722**	**0.0283**	0.9515	0/0488	**1**	**0**	0.9874	0.0127
Salt & Pepper Noise 0.001	0.9822	0.0176	**1**	**0**	1	0	**1**	**0**
Salt and Pepper Noise 0.003	0.9397	0.0596	**0.9990**	**0.0010**	1	0	**1**	**0**
Speckle Noise 0.01	0.7712	0.2266	**0.9951**	**0.0488**	1	0	**1**	**0**
Poisson Noise	0.8196	0.1807	**1**	**0**	1	0	**1**	**0**
Adjust	0.9950	0.0049	**1**	**0**	1	0	**1**	**0**
Histogram Equalization	0.9030	0.0957	**1**	**0**	1	0	**1**	**0**

Table 3: Comparison of NC values between Ernawan's scheme and our proposed scheme under geometrical attacks

Type of Attacks	Watermark 1				Watermark 2			
	Ernawan [6]		Proposed scheme		Ernawan [6]		Proposed scheme	
	NC	BER	NC	BER	NC	BER	NC	BER
Cropping rows off 25%	0.8100	0.1699	**0.8269**	**0.1563**	**0.8393**	**0.1475**	0.7700	0.2031
Cropping rows off 50%	0.6427	0.2900	**0.7452**	**0.2197**	**0.6471**	**0.2900**	0.6177	0.3086
Cropping columns off 25%	0.8824	0.1094	**0.9165**	**0.0791**	**0.8252**	**0.1592**	0.8121	0.1699
Cropping columns off 50%	0.8293	0.1543	**0.8757**	**0.1152**	**0.7363**	**0.2285**	0.7009	0.2539
Translate attack (10,20)	0.4063	0.4980	**0.4378**	**0.5127**	**0.4449**	**0.5146**	0.4096	0.5166
Scaling 0.5	0.9970	0.0029	**0.9970**	**0.0029**	1	0	**1**	**0**
Scaling 0.25	0.6520	0.3398	**0.8283**	**0.1621**	**0.9980**	**0.0020**	0.9267	0.0713

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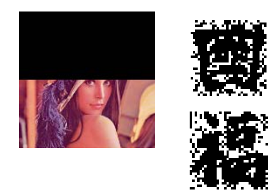
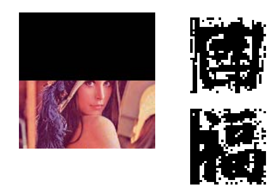
Table 4: Comparison of visual perception between Ernawan [6] and our scheme under differed type of attacks

Type of Attacks	Ernawan [6]	Our Scheme	Type of Attacks	Ernawan [6]	Our scheme
Gaussian Noise 0.005			Adjust		
Salt & Pepper Noise 0.003			Histogram Equalization		
Speckle Noise 0.01			Cropping rows off 25%		
Poisson Noise			Scaling 0.5		
Sharpening			JPEG Compression Q=50		

Our proposed scheme is tested under different types of signal processing attacks and geometrical attacks. Table 2 and Table 3 show the NC comparison between Ernawan's scheme [6] and proposed scheme under signal processing attacks and geometrical attacks respectively. Referring to Table 2, our scheme shows strong resistance against noise addition and histogram equalization for both extracted watermarks. According to Table 3, our scheme produces higher robustness on the first watermarks than Ernawan's scheme. While the second watermark still in not level of satisfaction against geometrical attacks. Our scheme produces higher robustness for both extracted watermarks under signal processing attacks.

The visual perception of the extracted watermark under different types of signal processing attacks and geometrical attacks are shown on Table 4. The experimental results show that our scheme can achieve high quality of the extracted both watermarks images. According to visual inspection of Table 4, the visual extracted watermarks from the proposed scheme has less distortion and it can be recognized by the human visual system. Ernawan's scheme [6] produces a large distortion against noise additions. Our scheme proves that it can produce high robustness of extracting multiple watermark after signal processing attacks.

6. CONCLUSION

This paper presents multiple watermarking techniques using RDWT-SVD. The embedding multiple watermarks occur in red and blue colors. The multiple watermarks are scrambled using Arnold transform before embedding into selected blocks. The watermark bits are embedded by modifying $U_{(2,1)}$ and $U_{(3,1)}$ component of the first column of U matrix with certain rules on each selected block. The proposed scheme is tested under different types of signal processing attacks, JPEG and JPEG2000 compression and geometrical attacks. The experimental results show that the proposed scheme produces high imperceptibility of watermarked image with the average SSIM value of 0.99. The both extracted watermark from red and blue colors achieve high resistance against compression attacks. Our scheme can achieve a higher robustness on both extracted watermarks other than existing scheme.

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