

Research on Color Watermarking Algorithm Based on RDWT-SVD

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ABSTRACT

In this paper, a color image watermarking algorithm based on Redundant Discrete Wavelet Transform (RDWT) and Singular Value Decomposition (SVD) is proposed. The new algorithm selects blue component of a color image to carry the watermark information since the Human Visual System (HVS) is least sensitive to it. To increase the robustness especially towards affine attacks, RDWT is adopted for its excellent shift in-variance. In addition, the SVD technique can also ensure the robustness due to the eminent properties of singular values. It is worth mentioning that the watermark information is not processed by SVD in embedding procedure, which prevents the occurrence of false positive detection. Meanwhile, to acquire a balance between imperceptibility and robustness, various scaling factor values are used towards different sub-bands. Experimental results show that the proposed algorithm has outstanding security, imperceptibility and robustness.

1. INTRODUCTION

With rapid development of Internet technology, network has become the mainstream platform of multimedia information interaction. Various forms of multimedia information, such as text, image, video and audio can be accessed or acquired conveniently. However, the negative impacts of the network also bother our life a lot. Recently, copyright disputes, malicious tampering and illegal communication occur more and more frequently, which hinder the development of the Internet to some degree. Therefore, it is necessary to design a security mechanism to solve these problems as soon as possible.

Digital watermarking is an effective method for copyright protection, which has become a hot topic in the area of information security in recent years [1]. Generally, a digital watermarking algorithm includes two sub-algorithms: watermark embedding algorithm and watermark extraction algorithm. The watermark embedding algorithm is applied to embed watermark information into host objects (such as text, image, audio and video). Usually, the so-called watermark

information is related to host objects it inclines to protect. The watermark extraction algorithm is executed to detect the watermark information, so as to realize the copyright protection of host objects. There are three major metrics for watermarking algorithms,

i) Security. A watermarking algorithm must be secure in designing procedure and avoid some security vulnerabilities, such as false positive detection [2-4];

ii) Imperceptibility. It is also called invisibility, which means the addition of watermark information won't change the host objects a lot, at least from human sense;

iii) Robustness. A robust watermarking algorithm has the ability to resist common malicious attacks, i.e. the watermark information won't erase easily by illegal users.

At present, designing a watermarking algorithm with strong security, imperceptibility and robustness has attracted much attention. Based on different operation domains, the watermarking algorithms fall into two classes, i.e. spatial watermarking and transform watermarking [4]. Spatial watermarking manipulates the pixel values by directly embedding the

watermark information into the host image. This method is easy to realize, but performs poorly under malicious attacks, such as least significant bit (LSB) based watermarking [5, 6] and Patchwork based watermarking [7, 8]. Transform watermarking firstly acquires transform domain coefficients of the host image using classical transform methods, and then adds watermark information to the coefficients. The common transform methods include Finite Ridgelet Transform (FRIT) [9], Discrete Cosine Transform (DCT) [10], Discrete Fourier Transform (DFT) [11], Discrete Wavelet Transform (DWT) [12], and RDWT [4, 13]. Compared to the spatial watermarking, transform watermarking has higher computational complexity, but it is equipped with preferable imperceptibility and robustness, so gets more widely used. SVD is an important matrix decomposition technique. The most notable feature of this technique is that singular values won't change a lot even under malicious attacks. However, if the SVD technique is applied separately to the watermarking algorithm, the computational complexity will be greatly increased. Therefore, many watermarking algorithms combining SVD with other transform methods, appear in [4]. Generally, a watermarking algorithm including two or more techniques are also called hybrid watermarking algorithm.

In [14], Ganic et al. proposed a watermarking algorithm based on DWT-SVD. They embedded the singular values of watermark image into the singular values of all DWT level-1 sub-bands, which enhances the imperceptibility and robustness effectively. But due to down-up sampling of sub-bands, DWT changes the signal distribution a lot, i.e. it is shift variant. Thus, the DWT based watermarking algorithm cannot resist affine attacks, such as rotation, scale, translation and shear. In order to overcome the disadvantage of DWT method, Lagzian et al. [13] replaced DWT with RDWT and kept the same embedding procedure as in [14]. Based on the shift invariant of RDWT, the improved algorithm is robust under affine attacks. But unfortunately, the SVD decomposition on watermark image induces a serious security issues, namely, false positive detection. So the referred two watermarking algorithms are insecure [4]. In [12], Lai et al. introduced an improved watermarking algorithm based on DWT-SVD. They firstly applied DWT level-1 to host image and separated the watermark image into two parts, then embedded each part into the singular values of the LH and HL sub-bands. Although the security issue gets solved, the robustness of Lai's scheme is still limited by DWT method. In [4], Markbol et al. proposed a watermarking algorithm based on RDWT-SVD. With the introduction of RDWT, the robustness of the algorithm is improved significantly. Meanwhile, the watermark image is not processed by SVD in

embedding procedure, which guarantees the algorithm security. In 2014, a color watermarking algorithm which integrated DWT, SVD and Arnold transform was proposed by George et al. [15]. Their scheme is secure and can be used more widely, but the robustness is still limited by DWT method.

In view of the above matters, in this paper we present a secure color watermarking algorithm based on RDWT-SVD. Firstly, the host image is split and three components of red, green and blue are obtained. Due to the HVS is least sensitive to the blue component, thus we perform RDWT level-1 on it and we get four sub-bands of *LL*, *LH*, *HL*, and *HH*. Secondly, we apply SVD to all sub-bands and directly embed the blue component extracted from the watermark image into the singular values. Note that various scaling factor values are adopted in the embedding procedure to achieve an outstanding imperceptibility. Moreover, the new algorithm gains a high level of security and is robust even under affine attacks.

The rest of this paper is organized as follows. Section 2 clarifies some basic preliminaries, such as RDWT and SVD. The details of the new proposed color watermarking algorithm are presented in Section 3. Experimental results and analysis are given in Section 4. Finally, a conclusion is drawn.

2. PRELIMINARIES

A. Redundant Discrete Wavelet Transform

Discrete Wavelet Transform (DWT) is a multiresolution analysis method, which can decompose the host image in a hierarchical manner and can fully reflect its time-frequency characteristics. In addition, this method matches the HVS well, so it is popular in watermarking algorithm designing. But DWT has a fatal disadvantage, i.e. shift variant. This flaw is caused by up-down sampling of the bands after filtering. Thus, the wavelet coefficients will change significantly even the signal has a minor shift, which limits the robustness of DWT based watermarking algorithms a lot.

RDWT, also called Over-complete DWT (ODWT), Shift Invariant DWT (SIDWT), Discrete Wavelet Frames (DWF) and Undecimated DWT (UDWT), can overcome the disadvantage of DWT for its excellent shift invariant. In RDWT analysis and synthesis process, it doesn't need sampling on host signal. Moreover, the redundancy of host signal can be fully used, which will enhance the noise resistance performance greatly. Next, the details of analysis and synthesis of 1D DWT and RDWT are described as follows [4, 16],

1) DWT analysis

$$c_j[k] = (c_{j+1}[k] * h[-k]) \downarrow 2, \quad (1)$$

$$d_j[k] = (c_{j+1}[k] * g[-k]) \downarrow 2, \quad (2)$$

where $h[-k]$ and $g[-k]$ indicate the low-pass and high-pass analysis filters, c_j and d_j represent the low-band and high-band output coefficients at level j , $*$ and $\downarrow$ denote convolution and down sampling.

2) DWT synthesis

$$c_{j+1}[k] = ((c_j[k] \uparrow 2) * h[k] + (d_j[k] \uparrow 2) * g[k]), \quad (3)$$

where $h[k]$ and $g[k]$ indicate the low-pass and high-pass synthesis filters, $\uparrow$ denotes up sampling. 1D DWT and its inverse are shown in Fig. 1(a).

$$d_j[k] = (c_{j+1}[k] * g_j[-k]). \quad (5)$$

4) RDWT synthesis

$$c_{j+1}[k] = \frac{1}{2} (c_j[k] * h_j[k] + d_j[k] * g_j[k]), \quad (6)$$

Fig. 1(b) shows the 1D RDWT and its inverse.

From Fig. 1, we can clearly know that the RDWT leaves out up-down sampling of each obtained band, and this is why it performs better than DWT. The DWT and RDWT level-1 decomposition on 512*512 Lena image are shown in Fig. 2 for better understanding of

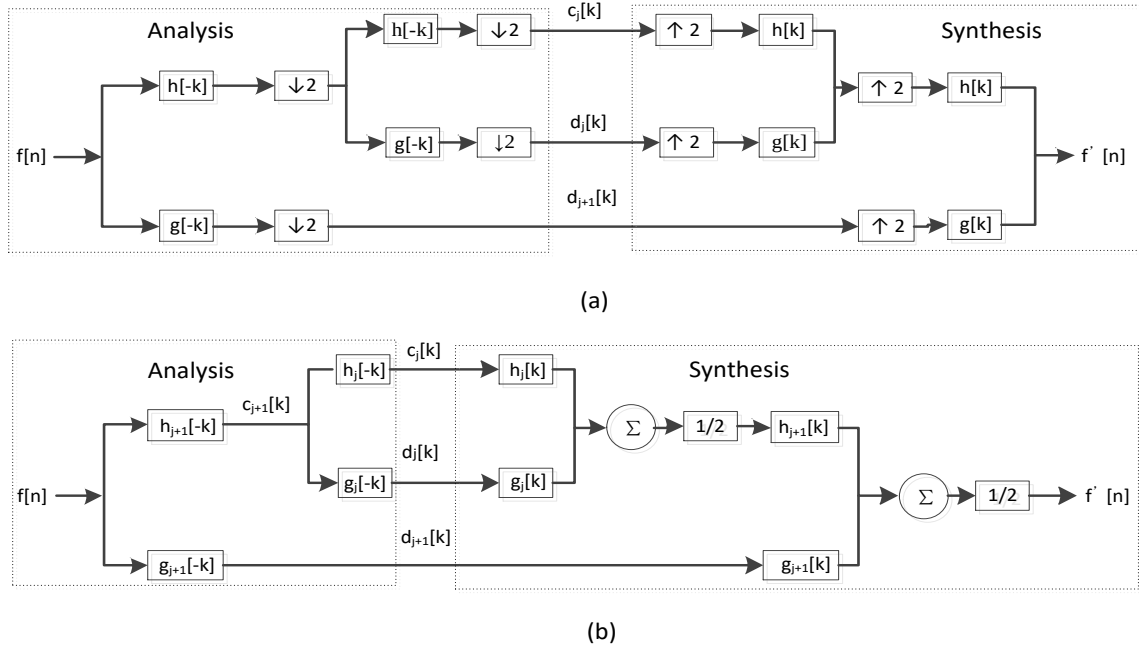


Figure 1: (a) 1D DWT analysis and synthesis filter banks; (b) 1D RDWT analysis and synthesis filter banks.

B. Singular Value Decomposition

SVD is a useful linear algebra tool, which is widely applied in image compression, digital watermarking and other signal processing areas. For a host image H of size $n \times n$, perform SVD on it will get,

$$H \Rightarrow U * S * V^T \quad (7)$$

where U and V are called orthogonal matrices, S denotes a diagonal matrix and its elements are arranged in a descending order, The extensive applications of SVD technique benefit from several excellent properties of singular values [17],

$$S(1,1) \geq S(2,2) \geq \dots \geq S(n,n) \geq 0 \quad (8)$$

3) RDWT analysis

$$c_j[k] = (c_{j+1}[k] * h_j[-k]), \quad (4)$$

- i) Few singular values concentrate most of the energy of a host signal;
- ii) Singular values have good ability to resist noise, i.e. the addition of a minor disturbance to the host signal won't change its singular values greatly;
- iii) Singular values represent the intrinsic linear features of a matrix;
- iv) Both square and rectangular matrices can be applied to SVD to calculate their singular values.

3. PROPOSED COLOR WATERMARKING ALGORITHM

A. Watermark embedding algorithm

The details of watermarking algorithm are described as follows,

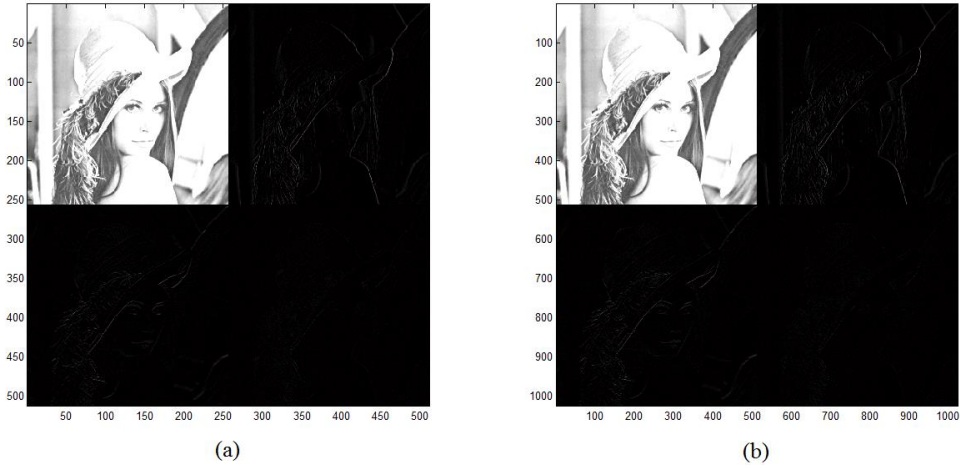


Figure 2: (a) DWT level-1; (b) RDWT level-1.

- 1) Split the host image H and get three color components, denoted as R , G and B ;
- 2) Apply RDWT level-1 to B component and generate four sub-bands: LL , LH , HL and HH ;
- 3) Apply SVD on all obtained sub-bands,

$$D \Rightarrow U_D * S_D * V_D^T \quad (9)$$

where D represents four sub-bands, i.e. LL , LH , HL and HH ;

- 4) Split color watermark image W and indicate the obtained components as R_w , G_w and B_w ;

- 5) Embed the B_w into singular values of each sub-band directly,

$$S'_D = S_D + \alpha B_w \quad (10)$$

where α is scaling factor. And then apply SVD to S'_D ,

$$S'_D \Rightarrow U_w^D * S_w^D * V_w^{DT} \quad (11)$$

- 6) Replace S_D with S_w^D and apply inverse SVD to get the watermarked sub-bands,

$$U_D * S_w^D * V_D^T \Rightarrow D' \quad (12)$$

- 7) Apply inverse RDWT to obtain watermarked B' ;

- 8) Merge all color components to get watermarked image H_w .

The process of watermark embedding is shown in Fig. 3(a).

B. Watermark extraction algorithm

The watermarked image may be maliciously attacked by an illegal user during the transmission, denoted as H_w^* . The details of watermark extraction are described as follows,

- 1) Split distorted watermarked image H_w^* and obtain the blue component B'^* ;
- 2) Perform RDWT level-1 on B'^* and obtain four

watermarked sub-bands, indicted to $LL1$, $LH1$, $HL1$ and $HH1$;

- 3) Apply SVD to all watermarked sub-bands,

$$D1 \Rightarrow U_{D1} * S_{D1} * V_{D1}^T \quad (13)$$

where $D1$ represents four sub-bands, i.e. $LL1$, $LH1$, $HL1$ and $HH1$;

- 4) Apply inverse SVD to obtain the referenced S_D'' ,

$$U_w^D * S_{D1} * V_w^{DT} \Rightarrow S_D'' \quad (14)$$

- 5) Extract the watermark information,

$$B_w^{D*} = (S_D'' - S_D) / \alpha \quad (15)$$

where B_w^{D*} denotes as watermark information extracted from four watermarked sub-bands.

- 6) Merge all the watermark color components to obtain watermark image W^* .

The process of watermark extraction is shown in Fig. 3(b).

4. EXPERIMENTAL RESULTS AND ANALYSIS

To test the performance of the proposed algorithm, a series of experiments have been done. All experiments are executed based on MATLAB platform, which select four color images (Lena, Baboon, Barbara, and Peppers) of size 512*512 as host image, and select color image Cat of size 512*512 as watermark image. They are all shown in Fig. 4.

In the watermark embedding process, two various scaling factor values are adopted for an outstanding algorithm performance [4], which defined as (16). The obtained watermarked images are shown in Fig. 5.

$$\alpha = \begin{cases} 0.05, & D = LL, \\ 0.005, & D = LH, HL, HH. \end{cases} \quad (16)$$

Security, imperceptibility and robustness are three important metrics to evaluate the performance of a

watermarking algorithm.

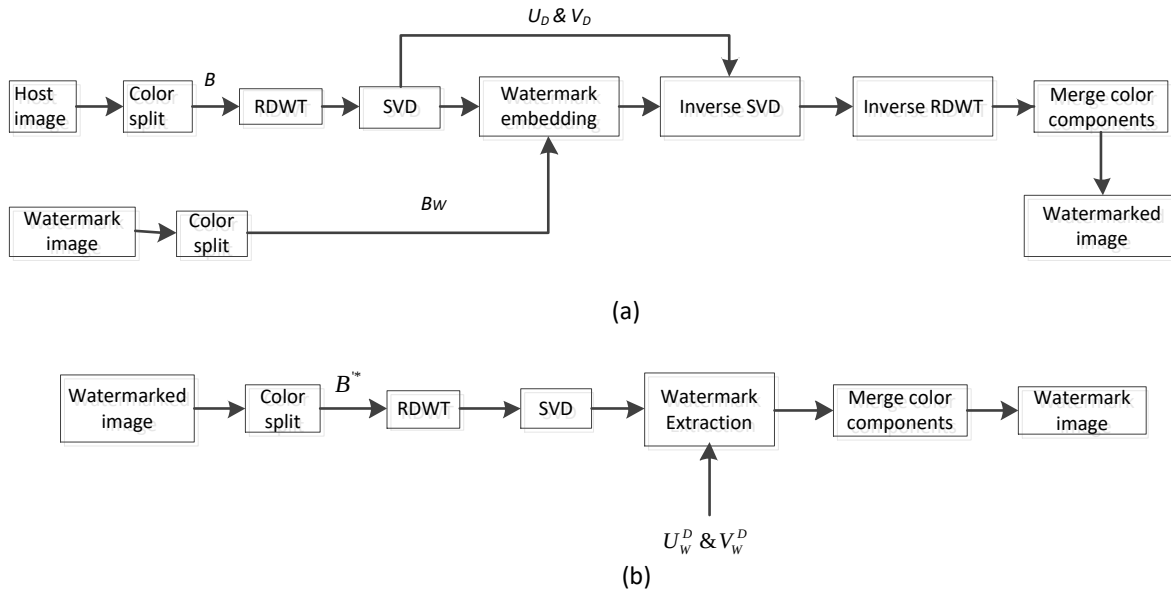


Figure 3: (a) The block of watermark embedding; (b) The block of watermark extraction.



Figure 4: (a)-(d) Host image; (e) Watermark image.

Since the watermark information is not processed by SVD in the watermark embedding procedure, the new algorithm won't lead to false positive detection [4]. Peak Signal to Noise Ratio (PSNR) and Correlation Coefficient (CC) are two most commonly used parameters to measure imperceptibility and robustness, which defined as (17) and (18).

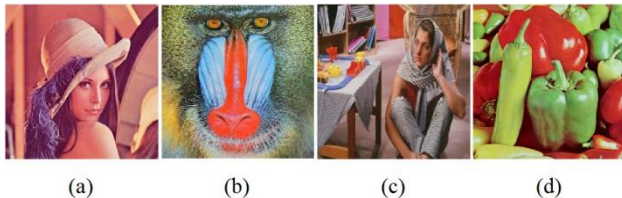


Figure 5: (a)-(d) Watermarked image.

$$PSNR = 10 \log \frac{(\max(I_{ijk}))^2 * x * y * 3}{\sum_{i=1}^x \sum_{j=1}^y \sum_{k=1}^3 (I_{ijk} - I'_{ijk})^2} \quad (17)$$

where I_{ijk} and I'_{ijk} are host image and watermark image, $x*y*3$ represents their size. The value of PSNR in decibels (dB) shows the similarity between host image and watermarked image. Usually, the visual quality of an image is not affected if the PSNR value is above 35dB [15].

$$CC = \frac{\sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^3 w(i, j, k) * w'(i, j, k)}{\sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^3 w^2(i, j, k)} \quad (18)$$

where $w(i, j, k)$ and $w'(i, j, k)$ indicate to original watermark image and extracted watermark image, $m*n*3$ represents their size. The CC value is between (0, 1), which estimates the ability of a watermarking algorithm to withstand malicious attacks. The acceptable CC value is about 0.7 or above [15].

The comparison of PSNR values computed using (17) between our algorithm and George algorithm [15] are presented in Table 1.

TABLE 1
THE PSNR VALUES OF OUR ALGORITHM AND GEORGE ALGORITHM

	Lena	Baboon	Barbara	Peppers
George algorithm	33.2	31.40	36.80	36.00
Our algorithm	46.04	42.68	40.23	43.49

In order to estimate the robustness of our new algorithm, the watermarked image is exposed to a set of attacks, such as salt & pepper noise, Gaussian noise,

mean, median and Gaussian filtering, contrast stretching, histogram equalization, JPEG compression, cut and affine transformation (such as translation, rotation, scaling and shear).

Take Lena as an example, the watermarked images after suffering various attacks are shown in Fig. 6 while the extracted watermark images are shown in Fig. 7.

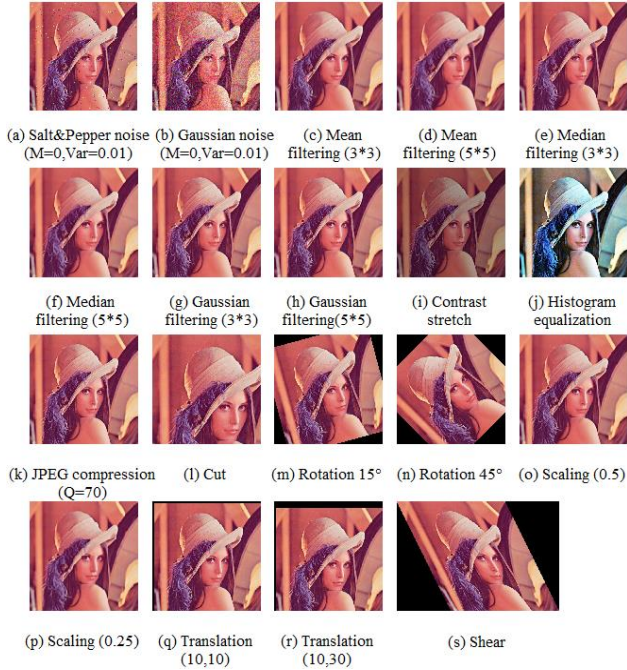


Figure 6: Watermarked images under various attacks.

According to [18], the CC values of extracted watermark images from four distorted watermarked images are calculated. They are presented in Table 2-5.

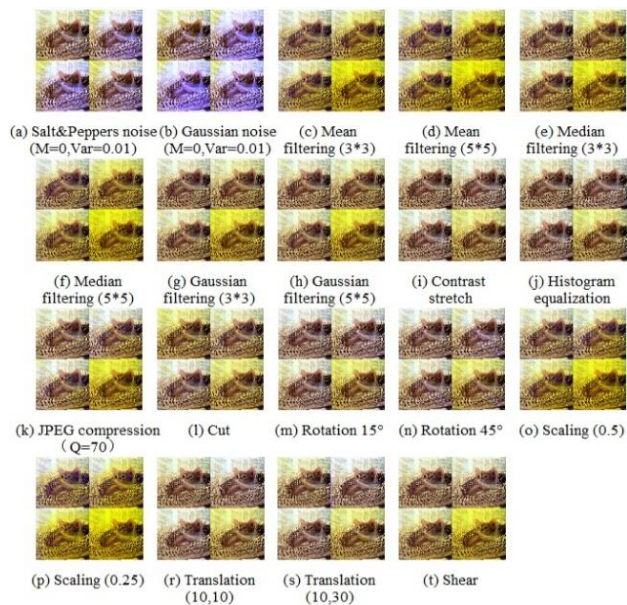


Figure 7: Extracted watermark images from the distorted watermarked images.

TABLE 2
THE CC VALUES OF EXTRACTED WATERMARK IMAGES FROM
DISTORTED WATERMARKED LENA IMAGE

Attacks	LL	LH	HL	HH
Salt & Peppers noise (M=0, Var.=0.01)	0.9862	0.8078	0.8385	0.8409
Gaussian noise (M=0, Var.=0.01)	0.9531	0.6211	0.6684	0.6568
Mean filtering (3*3)	0.9954	0.9653	0.9862	0.8647
Mean filtering(5*5)	0.9911	0.9751	0.9930	0.8598
Median filtering(3*3)	0.9990	0.9913	0.9995	0.8611
Median filtering(5*5)	0.9975	0.9945	0.9908	0.8568
Gaussian filtering(3*3)	0.9975	0.9978	0.9996	0.8712
Gaussian filtering(5*5)	0.9975	0.9979	0.9996	0.8712
Contrast stretch	0.9996	0.9717	0.9743	0.9636
Histogram equalization	0.9996	0.9717	0.9743	0.9636
JPEG compression(Q=70)	0.9967	0.9761	0.9657	0.8796
Cut	0.9568	0.9596	0.9851	0.9388
Rotation 15°	0.9552	0.9391	0.9631	0.9558
Rotation 45°	0.9676	0.9584	0.9790	0.9582
Scaling(0.5)	0.9979	0.9739	0.9787	0.8728
Scaling(0.25)	0.9967	0.9816	0.9863	0.8636
Translation(10, 10)	0.9967	0.9377	0.9687	0.9605
Translation(10,30)	0.9931	0.9384	0.9753	0.9561
Shear	0.9976	0.9941	0.9921	0.8711

From the observation of the above Tables, we can draw a conclusion that our algorithm is robust even for affine attacks, which is superior to most of the state of art. Moreover, the comparison of CC values between our algorithm and George algorithm [15] is shown in Fig. 8. As George et al. just embedded watermark information into LL sub-band, hence, we only take LL sub-band into consideration in designing comparison experiment.

TABLE 3
THE CC VALUES OF EXTRACTED WATERMARK IMAGES FROM
DISTORTED WATERMARKED BABOON IMAGE

Attacks	LL	LH	HL	HH
Salt & Peppers noise (M=0, Var.=0.01)	0.9956	0.8987	0.8906	0.9083
Gaussian noise (M=0, Var.=0.01)	0.9849	0.7980	0.7813	0.7774
Mean filtering (3*3)	0.9945	0.8960	0.9226	0.9696
Mean filtering(5*5)	0.9946	0.9753	0.9084	0.9765
Median filtering(3*3)	0.9890	0.9254	0.9507	0.9373
Median filtering(5*5)	0.9821	0.8947	0.9257	0.9587
Gaussian filtering(3*3)	0.9993	0.9588	0.9716	0.9285
Gaussian filtering(5*5)	0.9992	0.9587	0.9715	0.9285
Contrast stretch	0.9994	0.9665	0.9695	0.9814
Histogram equalization	0.9994	0.9665	0.9695	0.9814
JPEG compression(Q=70)	0.9948	0.9696	0.9898	0.9160
Cut	0.9842	0.9446	0.9518	0.9491
Rotation 15°	0.9674	0.9828	0.9763	0.9686
Rotation 45°	0.9755	0.9992	0.9871	0.9658
Scaling(0.5)	0.9920	0.8906	0.9189	0.9772
Scaling(0.25)	0.9865	0.8658	0.8987	0.9833
Translation(10, 10)	0.9985	0.9718	0.9654	0.9780
Translation(10,30)	0.9928	0.9754	0.9777	0.9746
Shear	0.9997	0.9819	0.9705	0.9205

TABLE 4
THE CC VALUES OF EXTRACTED WATERMARK IMAGES FROM
DISTORTED WATERMARKED BARBARA IMAGE

Attacks	LL	LH	HL	HH
Salt & Peppers noise (M=0, Var.=0.01)	0.9870	0.8177	0.8374	0.8827
Gaussian noise (M=0, Var.=0.01)	0.9644	0.6659	0.7261	0.7329
Mean filtering (3*3)	0.9925	0.9914	0.9632	0.8763
Mean filtering(5*5)	0.9865	0.9993	0.9496	0.8805
Median filtering(3*3)	0.9967	0.9912	0.9788	0.8633
Median filtering(5*5)	0.9937	0.9914	0.9639	0.8710
Gaussian filtering(3*3)	0.9968	0.9911	0.9924	0.8619
Gaussian filtering(5*5)	0.9968	0.9910	0.9924	0.8619
Contrast stretch	0.9975	0.9560	0.9229	0.9572
Histogram equalization	0.9975	0.9560	0.9229	0.9572
JPEG compression(Q=70)	0.9969	0.9911	0.9919	0.8742
Cut	0.9692	0.9774	0.9798	0.8796
Rotation 15°	0.9873	0.9257	0.9431	0.9814
Rotation 45°	0.9830	0.8989	0.9807	0.9861
Scaling(0.5)	0.9962	0.9876	0.9557	0.8788
Scaling(0.25)	0.9927	0.9981	0.9434	0.8837
Translation(10, 10)	0.9997	0.9490	0.9195	0.9556
Translation(10,30)	0.9963	0.9500	0.9267	0.9503
Shear	0.9978	0.9941	0.9840	0.8626

TABLE 5
THE CC VALUES OF EXTRACTED WATERMARK IMAGES FROM
DISTORTED WATERMARKED PEPPERS IMAGE

Attacks	LL	LH	HL	HH
Salt & Peppers noise (M=0, Var.=0.01)	0.9825	0.7945	0.8034	0.7874
Gaussian noise (M=0, Var.=0.01)	0.9604	0.6579	0.6685	0.6529
Mean filtering (3*3)	0.9930	0.9811	0.9913	0.8517
Mean filtering(5*5)	0.9855	0.9829	0.9977	0.8501
Median filtering(3*3)	0.9967	0.9996	0.9965	0.8485
Median filtering(5*5)	0.9930	0.9995	0.9951	0.8471
Gaussian filtering(3*3)	0.9967	0.9993	0.9996	0.8656
Gaussian filtering(5*5)	0.9967	0.9993	0.9996	0.8656
Contrast stretch	0.9997	0.9849	0.9879	0.9883
Histogram equalization	0.9997	0.9849	0.9879	0.9883
JPEG compression(Q=70)	0.9966	0.9811	0.9967	0.8562
Cut	0.9466	0.9998	0.9932	0.9447
Rotation 15°	0.9848	0.9607	0.9718	0.9743
Rotation 45°	0.9866	0.9863	0.9899	0.9493
Scaling(0.5)	0.9967	0.9757	0.9846	0.8561
Scaling(0.25)	0.9920	0.9743	0.9917	0.8538
Translation(10, 10)	0.9920	0.9815	0.9952	0.9776
Translation(10,30)	0.9858	0.9947	0.9989	0.9718
Shear	0.9972	0.9941	0.9962	0.8628

In Fig. 8, the horizontal ordinates 1-19 indicate to various attacks as applied in Tables 2-5. As shown in Figure 8, our algorithm is more robust than George algorithm, especially, the acquired ability to resist affine attacks.

5. CONCLUSION

In this paper, a color image watermarking algorithm based on RDWT-SVD is proposed. The blue component of a color image is selected to carry the watermark information, which can match the HVS well. In addition, taking advantage of the shift invariance of RDWT and eminent properties of singular values, the new algorithm acquires excellent robustness even for affine attacks.

6. ACKNOWLEDGMENT

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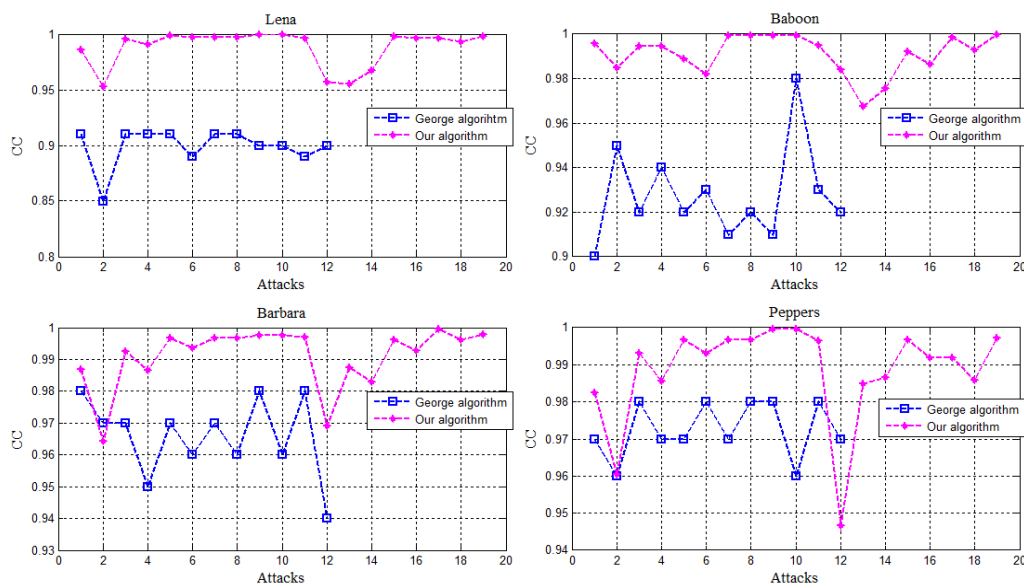


Figure 8: Comparison of CC values between our algorithm and George algorithm.

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