A New Robust Watermarking Scheme Based on RDWT-SVD

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Abstract

In this paper, a new method for non-blind image watermarking that is robust against affine transformation and ordinary image manipulation is presented. The suggested method presents a watermarking scheme based on redundant discrete wavelet transform and Singular Value Decomposition. After applying RDWT to both cover and watermark images, we apply SVD to the LL subbands of them. We then modify singular values of the cover image using singular values of the visual watermark. The advantage of the proposed technique is its robustness against most common attacks. Analysis and experimental results show higher performance of the proposed method in comparison with the DWT-SVD method.

Keywords: *Digital Image Watermarking, Redundant Discrete Wavelet Transform, Singular Value Decomposition*

1. Introduction

Watermarking (data hiding) is the process of embedding data into a multimedia element such as image, audio or video for security purposes or copyright protection. This embedded data can later be extracted from, or detected in the multimedia. A watermarking algorithm consists of an embedding algorithm, and an extraction, or detection algorithm. The type of information needed by the detector is an important criterion in classification of watermarking schemes**:**

- Non-blind schemes require both the original image and the secret key(s) for watermark embedding.
- Semi-blind schemes require the secret key(s) and the watermark itself.
- Blind schemes require only the secret key(s) [1].

Watermarking can be performed in the spatial or transform domain. Spatial domain methods are less complex but are not as robust as transform domain methods against various attacks [2]. One of the most common techniques in transform domain watermarking is to modify the coefficients obtained from singular value decomposition (SVD) of the cover image. The SVD based watermarking algorithm was first presented by Liu et al. [3]. In this algorithm, the authors after applying singular value decomposition to the cover image modify these coefficients by adding the watermark. They apply SVD transform again on the resultant matrix for finding the modified singular values. These singular values were combined with the known component to get the watermarked image. In another similar work, Chandra et al. [4], embed singular values of the watermark in the singular values of entire host image. The most important drawback of SVD-based algorithms is quality degradation of the watermarked image. In addition, the extracted watermark is not robust enough against common attacks in SVD-based algorithms. Thus researchers, usually combine SVD with other algorithms such as DCT and DWT.

In [5], authors combined DWT with SVD technique. In that paper, after decomposing the host image into four sub-bands, applied SVD to each sub-band and embedded singular values of the watermark into the sub-bands. In [6] DWT is combined with SVD technique to hide singular values of watermark in high frequency band (HH) of an image. When DWT is combined with SVD technique the watermarking algorithm outperforms the conventional DWT algorithm with respect to robustness against Gaussian noise, compression and cropping attacks [7]. Despite good performance of DWT methods in Watermarking, they suffer from drawbacks which are mentioned in section 2. To overcome the drawbacks of DWT based watermarking, one solution is the use of Redundant Discrete Wavelet Transform (RDWT).

The paper is organized as follows. In sections 2 and 3, RDWT and SVD transforms are explained respectively. In section 4, the proposed embedding and extraction algorithms are introduced. Experimental results are presented in section 5 and finally the conclusion is given in section 6.

2. RDWT

One of the most common methods used for watermarking is DWT, but one of the main drawbacks of this method is that because of the down-sampling of its bands, it does not provide shift invariance. This causes a major change in the wavelet coefficients of the image even for minor shifts in the input image. The shift variance of DWT causes inaccurate extraction of the cover and watermark image [8], since in watermarking, we need to know the exact locations of where the watermark information is embedded, to overcome this problem, researchers have proposed using Redundant Discrete Wavelet Transform.

To describe RDWT, a 1D DWT and RDWT with their inverses are illustrated in figure 1 [9]. Where f[n] and $f'[n]$ are the input and reconstructed signals. h[-k] and g[−k] are the lowpass and highpass analysis filters and h[k] and g[k] are the corresponding lowpass and highpass synthesis filters. cj and dj are the low-band and high-band output coefficients at level j. RDWT analysis and synthesis are given by[9] as follows:

a) Analysis:

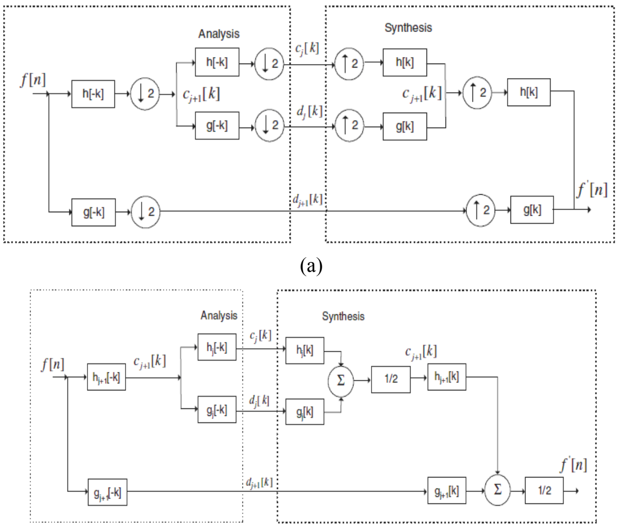
$$c_j[k] = (c_{J+1}[k] * h_j[-k])$$

$$d_j[k] = (c_{J+1}[k] * g_j[-k]) \tag{1}$$

b) Synthesis:

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

Where $*$ denotes convolution. RDWT eliminates downsampling and upsampling of coefficients during each filter-bank iteration. Redundant representation of the input sequence is obtained by eliminating downsampling in the RDWT analysis. Since frame expansion increases robustness with respect to additive noise, RDWT based signal processing is more robust than DWT method.



(a)

(b)

Figure 1. (a) 1D DWT analysis and synthesis filter banks, (b) 1D RDWT analysis and synthesis filter banks [9]

3. SVD

The singular value decomposition of a matrix is a factorization of the matrix into a product of three matrices. Given an m×n matrix A, where m ≥ n, the SVD of A is defined as [10]

$$A = U\Sigma V^T \tag{3}$$

where U is an m×n column-orthogonal matrix whose columns are referred to as left singular vectors; $\Sigma = \mathrm{diag}(\sigma_1, \sigma_2, \ldots, \sigma_n)$ is an n×n diagonal matrix whose diagonal elements are nonnegative singular values arranged in descending order; V is an n×n orthogonal matrix whose columns are referred to as right singular vectors.

If rank (A) = r, then Σ satisfies $\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_r \geq \sigma_{r+1} = \sigma_{r+2} = \cdots \sigma_n = 0$.

SVD efficiently represents intrinsic algebraic properties of an image, where singular values correspond to brightness of the image and singular vectors reflect geometry characteristics of the image. Since slight variations of singular values of an image may not affect the visual perception, watermark embedding through slight variations of singular values in the segmented image has been introduced as a choice for robust watermarking [11].

4. Proposed method: RDWT-SVD based Watermarking

4.1. Watermark embedding:

The proposed watermark embedding algorithm is shown in figure 2.

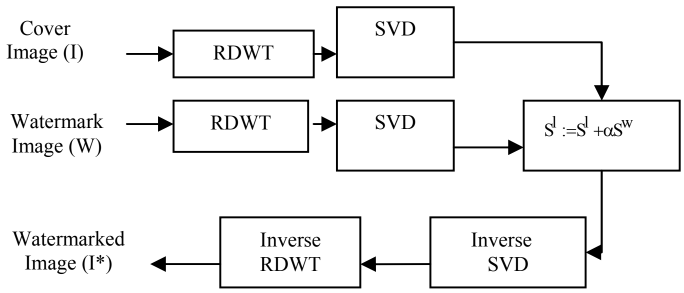


Figure 2. Block Diagram of the proposed watermark embedding algorithm

The steps of watermark embedding algorithm are as follows:

1. Apply RDWT to the cover image to decompose it into LL, HL, LH, and HH subbands.

2. Apply SVD to the low frequency subband LL of the cover image:
$I^l = U^l S^l V^l$

3. Apply RDWT to the visual watermark.

4. Apply SVD to the low frequency subband of watermark:
$W = U^w S^w V^w$

5. Modify the singular values of the cover image with the singular values of watermark image
$S^{*l} := S^l + \alpha S^w$

where α is scaling factor, S^l and S^w are the diagonal matrices of singular values of the cover and watermark images, respectively.

6. Apply inverse SVD on the transformed cover image with modified singular values
$I^{*l} = U^{l} S^{*l} V^{l}$

7. Apply inverse RDWT using the modified coefficients of the low frequency bands to obtain the watermarked image.

4.2. Watermark extraction:

The proposed watermark extracting algorithm is shown in figure 3.

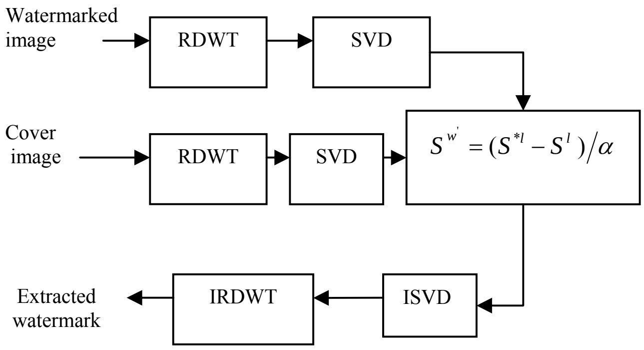


Figure 3. Block Diagram of the proposed watermark extracting algorithm

1. Using RDWT, decompose the watermarked image I^* into 4 subbands: HH, HL, LH and LL.
2. Apply SVD to low frequency subband LL: $I^{*l} = U^{*l} S^{*l} V^{*l}$.

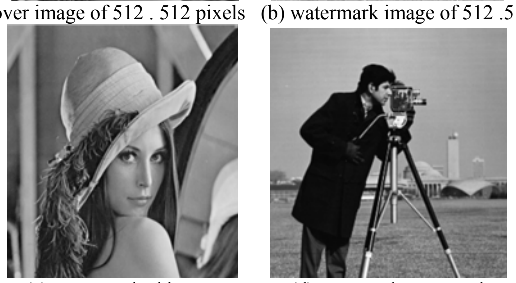
3. Extract the singular values from low frequency subband of watermarked and cover image: $S^{W'} = (S^{*l} - S^{l})/\alpha$ .where S^l contains the singulars of the cover image.

4. Apply inverse SVD to obtain low frequency coefficients of the transformed watermark image.
5. Apply inverse RDWT using the coefficients of the low frequency subband to obtain the watermark image.

5. Experimental results and discussion

In this study, we used gray scale Lena image as our host image of size 512x512, and the Cameraman for watermark image with same size. In our experiments, we used the scaling factor $\alpha = 0.25$. Fig. 4 shows cover image, watermark, watermarked image and the extracted watermark.

(a) cover image of 512 . 512 pixels (b) watermark image of 512 .512 pixels



(c) watermarked image (d) extracted watermark

Figure 4. (a) cover image (b) watermark image(c) watermarked image (d) extracted watermark

When watermarks are extracted, similarity of the watermarked and cover image can be defined by the PSNR (Peak Signal to Noise Ratio) criterion:

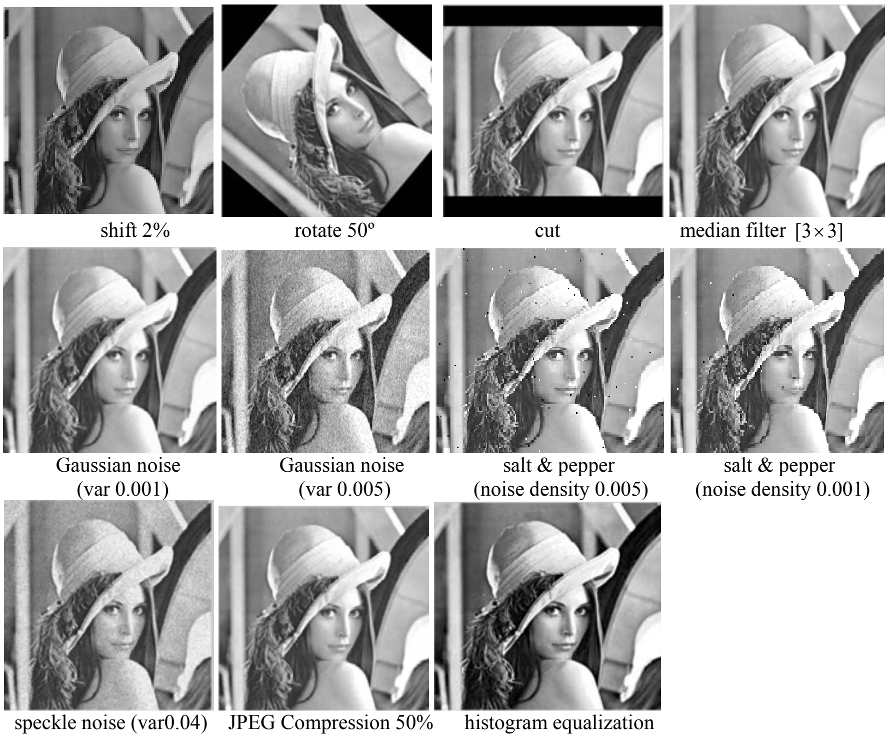
$$\mathrm{PSNR} = 10 * \log_{10}\left[\frac{\max((X(i,j))^2}{\mathrm{MSE}}\right] \tag{4}$$

Where MSE (Mean Square Error) is defined as:

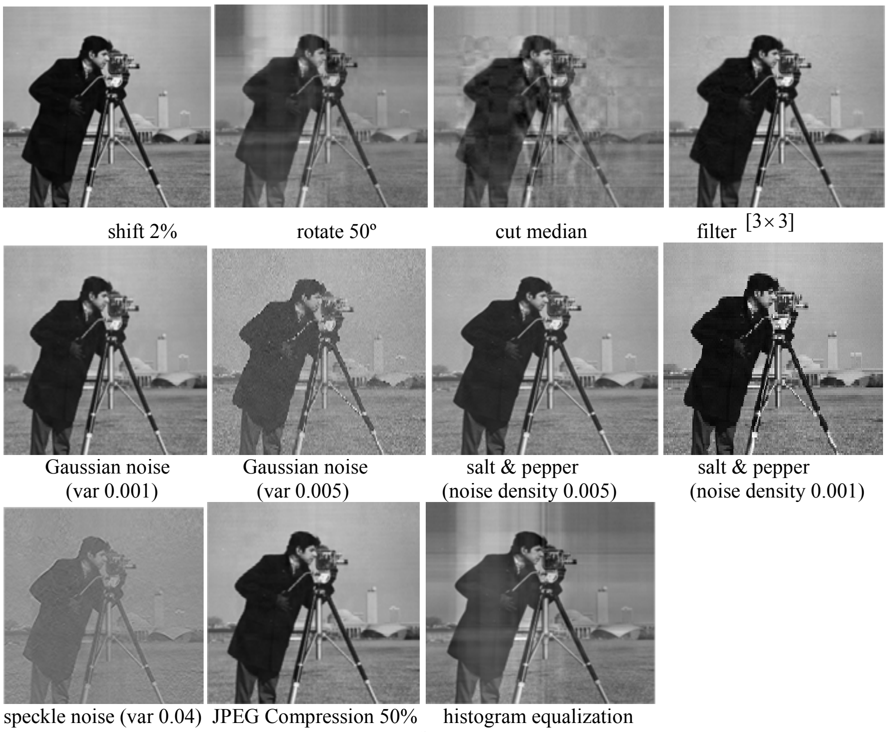
$$\mathrm{MSE} = \frac{1}{m*n}\sum_{i=1}^{m}\sum_{j=1}^{n}[X(i,j) - Y(i,j)]^2 \tag{5}$$

Where m and n are the dimensions of the images X and Y. PSNR is measured in db. Larger values of PSNR indicate better watermark concealment.

We compared the watermarked image with the original one and PSNR was obtained as 37.52 db. To investigate the robustness of the algorithm, the watermarked image was attacked by applying processing shift, rotation, cropping, median filtering, JPEG compression, Gaussian noise, salt & pepper noise, speckle noise and histogram equalization. The results of these attacks are shown in figure5.



(a)



(b)

Figure 5. (a) watermarked image under different attacks, (b) extracted watermarks

Also the comparison results of our method with DWT-SVD are summarized in Table 1. The numbers in table I indicate the PSNR and Correlation Coefficient between extracted watermarks and original ones. The standard correlation coefficient is obtained by equation (5).

$$\text{correlation} = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2}\sqrt{\sum (y-\bar{y})^2}} \tag{5}$$

As can be seen, our method (RDWT-SVD) works better than DWT-SVD for all attacks.

Table 1. Comparison between results of our method and DWT- SVD

	DWT-SVD		**RDWT-SVD**	
	CC	PSNR	CC	PSNR
Shift 2%	0.9987	31.19	0.9989	31.27
Rotate 50º	0.7607	3.34	0.8630	8.62
cut	0.5603	6.33	0.9512	11.07
Median filter $[3 \times 3]$	0.9839	26.44	0.9942	28.57
Gaussian noise (var 0.001)	0.9919	29.09	0.9971	29.27
Gaussian noise (var 0.005)	0.9191	19.08	0.9792	24.75
JPEG compression 50 %	0.9977	30.07	0.9983	30.84
salt & pepper (density 0.005)	0.9868	27.19	0.9959	30.25
salt & pepper(density 0.001)	0.9991	31.67	0.9985	32.28
speckle noise (var 0.04)	0.7466	13.32	0.8896	18.01
Histogram equalization	0.8519	4.73	0.8530	7.66

6. Conclusion

We presented a new watermarking method based on RDWT-SVD to embed a watermark image which can be as large as the cover image. Modifying singular values of the cover image in RDWT domain provides high robustness against common attacks. High PSNR and correlation coefficient of watermarked image is another beneficial point of the algorithm as the result of RDWT implementation. The results demonstrated that the proposed method is more robust to various attacks compared to DWT based methods. RDWT is shift invariant, and its redundancy introduces an over complete frame expansion. It is known that frame expansion increases robustness with respect to additive noise. Thus, RDWT based signal processing tends to be more robust than DWT based techniques. Another advantage of this method is the possibility to embed a large watermark in the cover image.

7. References

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