Blind Watermarking Scheme Using Singular Vectors Based on DWT/RDWT/SVD

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Abstract

We proposed a blind watermarking scheme using singular vectors based on Discrete Wavelet Transform (DWT) and Redundant Discrete Wavelet Transform (RDWT) combined with Singular Value Decomposition (SVD) for copyright protection application. We replaced the 1st left and right singular vectors decomposed from cover image with the corresponding ones from watermark image to overcome the false-positive problem in current watermark systems using SVD. The proposed scheme realizes the watermarking system without a false positive problem, and shows high fidelity and robustness.

1. Introduction

Currently multimedia contents are distributed over the Internet more and more, and protecting their legal copyright ownership becomes critical gradually. There have been many studies about using digital watermarks to solve the protection problem [1-4], and as a result contents owners can embed their logos or personal information into the multimedia contents to protect their copyrights.

SVD is widely used in digital watermarking schemes because its features are not affected much by common attacks such as compression, geometric operations, etc. Nasrin *et al.* applied SVD to each sub-band generated by the RDWT transform [5], and they achieved high fidelity and strong robustness for JPEG compression, common filtering, and geometric attacks. However, it is not robust to noise addition attack. Saeed *et al.* chose the third level sub-bands to perform SVD [6], and the sub-bands are generated by Radon transform. This method chose LH3 and HL3 sub-bands for embedding watermark, and its fidelity is very high, but its robustness is not strong for some general noise addition. In [7], Chih-Chin Lai used DWT and selected LH and HL sub-bands to apply SVD and embed watermark image directly into the singular value matrix. The similarity among these studies is that the singular values are employed mainly in the embedding process. The singular values are rarely changed to a small change in image intensity and the values are not much different among images. Because of the last feature, a scheme using singular values may cause the false positive problem. It means that adversaries can extract their fake watermark image to show their copyright ownership.

We proposed an image watermarking scheme using singular vectors based on DWT and RDWT combined with SVD. Specially, to solve the false positive problem generated by using SVD, the proposed scheme replaces the 1st left and right singular vectors decomposed from the cover image by the corresponding vectors decomposed from the watermark image.

The paper is organized as follows: in section 2, the background review including SVD, DWT and RDWT is illustrated, and the problem to solve through our study is presented. The proposed scheme is presented in section 3, and section 4 shows the simulation results and the comparison between the proposed system and existing systems.

2. Background Reviews and False Positive Problem

2.1 Background reviews

DWT and RDWT decompose an image into frequency channels of constant bandwidth on a logarithmic scale, and each transform can be implemented as a multistage transformation. An image is decomposed into four sub-bands denoted as LL, LH, HL and HH at the 1st level, where LH, HL, and HH represent the fine−level wavelet coefficients and LL stands for the coarse−level coefficients. RDWT is similar to DWT but it does not use down−sampling, and the dimension of each sub−band by DWT becomes a quarter of the cover image while the dimension of each sub−band by RDWT is the same as the cover image.

SVD is an effective method to decompose an image into a set of linear independent components. Cover image is decomposed into a diagonal matrix, S and two orthogonal matrices, U and V. Generally, the SVD transform can be applied to a whole image or a sub−image. The SVD of an image A is defined as Eq. (1)

$$A = USV^T = \sum_{k=1}^{k=r} \lambda_k u_k v_k^T \tag{1}$$

where U and V are orthogonal matrixes, and $S = \mathrm{diag}(\lambda_k)$ is a diagonal matrix of singular values λ_k, $k = 1,..,r$, which are arranged in decreasing order. $u_k's$ and $v_k's$ are called left and right singular vectors of an image A. It can be observed that SVD decomposes an image into layers of $\lambda_1 u_1 v_1^T, \lambda_2 u_2 v_2^T, \dots, \lambda_r u_r v_r^T$.

2.2 False Positive Problem

The U and V orthogonal matrices of an original watermark image are required for the watermark extraction algorithm to be combined with the diagonal matrix S decomposed from the received watermarked image. The false positive problem originates from this step because the singular values are so stable that any change to image intensity cannot affect much to the singular values themselves. Moreover, the singular values of different images are quite similar to each other, and attackers may use the diagonal matrix decomposed from the watermarked image to combine with their fake orthogonal matrices U_f and V_f to retrieve the watermark image. As a result, attackers can extract their fake watermark image successfully, and it can be a problem for the copyright protection application.

3. The proposed scheme

3.1 Watermark embedding algorithm

The proposed scheme applies 2DWT to the cover image A and RDWT to the watermark image W, and then applies SVD to HL2 sub−band A_1 and to HL1 sub−band W_1 as,

$$[U_{A_1}, S_{A_1}, V_{A_1}] = \mathrm{SVD}(A_1);\ [U_{W_1}, S_{W_1}, V_{W_1}] = \mathrm{SVD}(W_1). \tag{2}$$

Secondly, it modifies the singular values of A_1 by embedding watermark W directly, and then applies SVD to them as

$$D = S_{A_1} + \alpha W;\ [U_D, S_D, V_D] = \mathrm{SVD}(D) \tag{3}$$

where α is a scale factor.

Thirdly, it replaces 1st left and right singular vectors of the cover image with the corresponding vectors decomposed from the watermark image as

$$\left(U_{A_1}\right)_1 = \left(U_{W_1}\right)_1, \text{ and } \left(V_{A_1}\right)_1 = \left(V_{W_1}\right)_1 \tag{4}$$

where,

$$U_{A_1} = \left[\left(U_{A_1}\right)_1 \left(U_{A_1}\right)_2 \cdots \left(U_{A_1}\right)_{\frac{N}{4}}\right],\ V_{A_1} = \left[\left(V_{A_1}\right)_1 \left(V_{A_1}\right)_2 \cdots \left(V_{A_1}\right)_{\frac{N}{4}}\right],$$

$$U_{W_1} = \left[\left(U_{W_1}\right)_1 \left(U_{W_1}\right)_2 \cdots \left(U_{W_1}\right)_{\frac{N}{4}}\right],\ V_{A_1} = \left[\left(V_{W_1}\right)_1 \left(V_{W_1}\right)_2 \cdots \left(V_{W_1}\right)_{\frac{N}{4}}\right].$$

Finally, it obtains the modified DWT coefficients by $(A_1)' = U_{A_1} S_D \left(V_{A_1}\right)^T$, and it finds the watermarked image A_W by applying $(2DWT)^{-1}$ to the 2DWT of a cover image replaced with $(A_1)'$.

3.2 Watermark extraction algorithm

The proposed scheme applies 2DWT to the received watermarked image A_W^*, and then applies SVD to 2HL sub−band $(A_W^*)_1$ using (5). If we define D^{*HL} as (6), the extracted watermark is obtained using (7).

$$\left[U_{(A_W^*)_1}, S_{(A_W^*)_1}, V_{(A_W^*)_1}\right] = \mathrm{SVD}((A_W^*)_1). \tag{5}$$

$$D^{*HL} = U_D S_{(A_W^*)_1} (V_D)^T. \tag{6}$$

$$W^* = \frac{\left(D^{*HL} - S_{(A_W^*)_1}\right)}{\alpha}. \tag{7}$$

To overcome the false−positive problem, it is necessary to calculate and compare the correlation values between $\left(U_{(A_W^*)_1}\right)_1$ and $\left(U_{W_1}\right)_1$, and between $\left(V_{(A_W^*)_1}\right)_1$ and $\left(V_{W_1}\right)_1$.

4. Simulation and results

The proposed scheme uses 'Lena' gray scale image with 512×512 resolution as a cover image. A watermark image, 'Cameraman', with 128×128 resolution is embedded into the cover image with PSNR of 45.46 dB, when the scale factor equals to 0.005 as given in Figure 1.

Figure 1. (a) Cover image (b) Watermark image (c) Watermarked image (PSNR=45.46).

It can be observed that the proposed scheme shows the acceptable PSNR value and the strongest robustness to most of attacks as shown in Tables 1.

Table 1. Fidelity and robustness comparison of the proposed system with previous studies.

Attacks	Lai *et al.* [7]	Nasrin *et al.* [5]	Proposed system
PSNR [dB] (No attack)	52.30	54.04	45.46
Salt and pepper	0.9567	0.8926	0.9664
Gaussian noise	0.9531	0.8935	0.9631
Speckle	0.9491	0.9520	0.9675
Average filter	0.9277	0.9820	0.9326
Gaussian filter	0.9347	0.9870	0.9565
Rotation [45^0]	0.9847	0.9815	0.9756
JPEG Q=20	0.9447	0.8929	0.9622
JPEG Q=30	0.9470	0.9223	0.9626
JPEG Q=40	0.9471	0.9355	0.9653
JPEG Q=50	0.9455	0.9470	0.9631
JPEG Q=70	0.9442	0.9670	0.9630
Contrast	0.9236	0.9320	0.9369
Cut 10	0.9274	0.9928	0.9769

In Figure 2, we note that ρ_A is the correlation coefficient between $(U_{(A_W^*)_1})_1$ and $(U_{W_1})_1$, ρ_B between $(\boldsymbol{U}_{(A_W^*)_1})_1$ and $(\boldsymbol{U}_{Wf_1})_1$, ρ_C between $(\boldsymbol{V}_{(A_W^*)_1})_1$ and $(\boldsymbol{V}_{W_1})_1$, and ρ_D between $(\boldsymbol{V}_{(A_W^*)_1})_1$ and $(\boldsymbol{V}_{Wf_1})_1$.

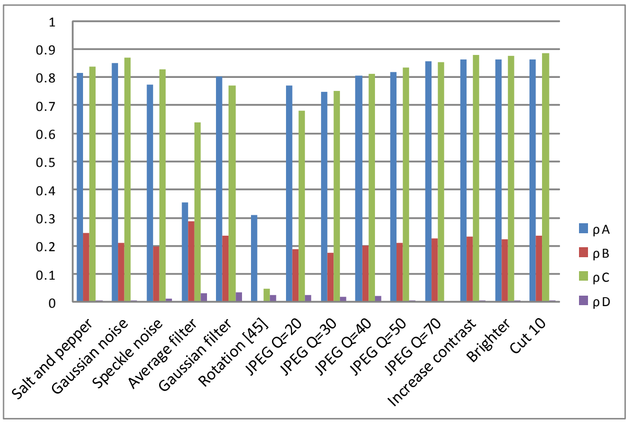

Figure 2. The simulation results for Lena cover image.

The proposed scheme gives strong robustness to most of attacks, except the rotation attack case. In Figure2, through the correlation coefficient values between the first left singular vectors of the watermarked image and the watermark image in the extraction process and the ones for the first right singular vectors, the proposed scheme can overcome the false positive problem. If the true watermark image is used for the extraction process, the correlation coefficients will be much higher than the case of using a fake watermark image.

5. Conclusion

This paper proposed an image watermarking system based on DWT/RDWT/SVD for the copyright protection application without false positive problem. Cover and watermark images are transformed by 2DWT and RDWT separately, and SVD is applied to a sub-band of each image. Moreover, the replacing components of singular vectors **U** and **V** between cover image and watermark image overcomes the false positive problems, which exist in watermark system using SVD. The proposed method gives higher robust than the previous systems. The experiment evaluation results show that the proposed systems give high fidelity and strong robustness against common attacks.

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