An Imperceptible Watermarking Scheme based on Double Density Dual-Tree Discrete Wavelet Transform in combination with Singular Value Decomposition

Mary Agoyi and Devrim Seral

Abstract - **Watermarking has been the current solution to Copyright protection and content authentication which has become a major issue in multimedia technology. This study introduces a multimedia watermarking technique based on the combination of double density Dual-Tree discrete wavelet transform (DD-DT-DWT) and singular value decomposition (SVD) method called DD-DT-DWT–SVD. An experiment is carried out to compare Watermarking technique based on DD-DT-DWT–SVD with that of the DWT-SVD. The experimental result shows that watermarking based on DD-DT-DWT–SVD is more imperceptible than watermarking based on DWT-SVD.**

Index Terms - **Watermarking, Discrete Wavelet Transform, Double Density Dual-Tree Discrete Wavelet Transform, Singular Value Decomposition**

I. INTRODUCTION

With the wide use of multimedia technologies and rapid popularity of the Computer and Internet technologies, digital multimedia contents are transmitted via the Internet and other computer technologies. This has lead to different kinds of infringements on the digital contents which include easy access, authorized manipulations, illegal copying, illegal reproduction of original contents and malicious attacks [1]. Digital watermarking is a technology that is known to help protect multimedia contents from illegal copying, manipulation and distribution problems by embedding an information into the digital multimedia content without it been noticed by visual representation [2]. Digital watermarking is grouped into spatial and frequency domain. The spatial domain embeds the watermark into the digital content by pixels modification. Although these technique has low complexity and is easy to implement but it is not robust against attacks and common signal processing operations such as rotating, scaling, cropping, filtering, additive noise and compression.

The frequency domain that is similar to spread spectrum communication embeds the watermark by modification of the magnitude coefficient of the digital content according to the embedding algorithm. Though the frequency domain watermarking has higher computational cost but it has proven to be more robust and imperceptible than the spatial domain watermarking [3]. Currently the discrete wavelet transform (DWT), discrete cosine transform (DCT) and the discrete Fourier transform (DFT) are the commonly used frequency domain watermarking, but the DWT is most widely used due to its frequency spread, multi resolution ability and the spatial localized nature of its wavelet [4]. Despite the advantages of DWT, it major drawbacks it that DWT is not shift invariant, small shift in the input signal can lead to variations in the distribution of energy at different scales between the coefficients of the DWT. The wavelets filters are also separable and real causing a poor directional selectivity for diagonal features [5]. In other to overcome this shortcoming double density Dual Tree discrete (DD-DT-DWT) wavelet transform can be used. Double density dual tree DWT processes the properties of double density DWT and dual tree complex DWT. It is based on FIR perfect construction filter banks. It is nearly shift invariant which solves the problem of wavelet coefficients oscillation around singularities [6]. A combination of DD-DT-DWT with singular value decomposition (SVD) can provide a better transparency and robustness. SVD thence to achieve better transparency and robustness since slight variations of singular value does not affect the visual perception of the cover image [1].

II. BACKGROUND REVIEW

A. DD-DT-DWT

The Double density Dual-Tree DWT structure consists of two over sampled iterated filter bank operating in parallel and it transform is based on two scaling functions and four distinct wavelets. It processes the properties of double density DWT and Dual Tree Complex DWT [6]. The Double density DWT is based on single scaling function and two distinct wavelets. A

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half is the offset factor from one wavelet to the other. The translation of one wavelets integer fall midway between the translation of the other wavelets integer [7], as expressed in (1)

$$\psi_2(t) \approx \psi_1(t-0.5) \quad (1)$$

The Dual Tree Complex DWT (DT-CWT) uses two trees of real filters to generate the real and imaginary parts of the wavelet coefficients separately [8][9]. It has Gabor-like complex value wavelets. This is usually obtained by the conducting of two DWT filter banks in parallel as the real and imaginary parts of a complex transform. The wavelet corresponding to each of the two DWTs form an appropriate Hilbert transforms pair [7] of the form of (2).

$$\psi_g(t) \approx H\{\psi_h(t)\} \quad (2)$$

The DT-CWT introduces limited redundancy and allows the transform to provide appropriate directionally selective filters while preserving the usual properties of perfect reconstruction and efficient computation upon the embedding algorithm. [10]. Both the double density DWT and the dual tree complex DWT are based on FIR perfect construction filter banks and they are nearly shift invariant. There development was motivated by a part of undecimated DWT and special properties of complex wavelet transform respectively. They both outperform the critically sampled DWT in several signal processing applications [11]

B. SVD

In SVD transformation, an image of n x n can be decomposed into three matrices that are of the same size as the original image. Let I be an image then the SVD of I can be given as (3)

$$[\mathrm{U\ S\ V}] = \mathrm{SVD(I)} \qquad \mathrm{I} = \mathrm{USV}^T \quad (3)$$

Where U and V are the orthogonal matrices with small singular value and S is a diagonal matrix with the larger singular value entries of the image [1].

The three main properties of SVD in digital image processing scheme are that:

1) When a small perturbation is added to an image it singular values do not change significantly due to the stability property of the singular value.
2) Pairs of singular vectors specify the geometry of the image and the singular value specifies the luminance of an image layer.
3) The intrinsic algebraic image properties is represented by the singular values [12]

III. THE PROPOSED APPROACH

The proposed DD-DT-DWT-SVD watermarking scheme is given as follows

A. Watermarking embedding

1) Apply DD-DT-DWT to the original image I to decompose it into sub bands. As given in (4)

$$[\mathrm{HH\ HL\ LH\ LL}] = \mathrm{DD\text{-}DT\text{-}DWT(I)} \quad (4)$$

Where HH is the high-high frequency band, HL is the high-low frequency band, LH is the low-high frequency band, and LL is the low-low frequency band.

2) Apply SVD to HH as given in (5)

$$[U_1 S_1 V_1] = \mathrm{SVD}(HH) \qquad HH = U_1 S_1 V_1^T \quad (5)$$

Where U1 and V1 are the orthogonal matrixes of the decomposed high frequency band image and S1 is the diagonal matrix with the higher entries of the decomposed high frequency band of the original image.

3) Apply SVD to the watermark image as given in (6)

$$[U_2 S_2 V_2] = \mathrm{SVD}(W) \qquad W = U_2 S_2 V_2^T \quad (6)$$

Where U2 and V2 are the orthogonal matrixes of the watermark image and S2 is the diagonal matrix with the higher entries of the watermark image.

4) Modify the singular value of the decomposed original image with the singular value of the watermark image using a scaling factor α, which controls the strength of the watermark to be inserted. This is given in (7)

$$S_3 = S_1 + aS_2 \quad (7)$$

5) The high frequency band of the decomposed image is modified thus given as (8)

$$HH_2 = U_1 S_3 V_1^T \quad (8)$$

6) Inverse DD-DT-DWT (IDD-DT-DWT) is applied to the decomposed image, using the modified high

frequency band HH2 instead of HH as shown in (9) to give the watermarked image

$$I = \text{IDD-DT-DWT}(\text{HH}_2 \ \ \text{HL} \ \ \text{LH} \ \ \text{LL}) \quad (9)$$

B. *Watermarking extraction*

1) Apply DD-DT-DWT to the watermarked image W to decompose it into sub bands. As given in (10)

$$[\text{HH}_W \ \text{HL}_W \ \ \text{LH}_W \ \ \text{LL}_W] = \text{DD-DT-DWT(W)} \quad (10)$$

Where HHw is the high-high frequency band, HLw is the high-low frequency band, LHw is the low-high frequency band, and LLw is the low-low frequency band of the decomposed watermarked image.

2) Apply DD-DT-DWT to the original image to decompose it into sub bands. As given in (11)

$$[\text{HH} \ \ \text{HL} \ \ \text{LH} \ \ \text{LL}] = \text{DD-DT-DWT(I)} \quad (11)$$

3) Apply SVD to the high frequency band of the decomposed image as given in (12)

$$[U_1 S_1 V_1] = \text{SVD}(HH)$$
$$HH = U_1 S_1 V_1^T \quad (12)$$

Where U1 and V1 are the orthogonal matrixes of the decomposed high frequency band image and S1 is the diagonal matrix with the higher entries of the decomposed high frequency band of the original image.

4) Apply SVD to the high frequency band of the decomposed watermarked image as given in (13)

$$[U_4 S_4 V_4] = \text{SVD}(HH_w)$$
$$HH_w = U_4 S_4 V_4^T \quad (13)$$

Where U4 and V4 are the orthogonal matrixes of the decomposed high frequency band image and S4 is the diagonal matrix with the higher entries of the decomposed high frequency band of the watermarked image.

5) Apply SVD to the watermark image as given in (14)

$$[U_2 S_2 V_2] = \text{SVD}(W)$$
$$W = U_2 S_2 V_2^T \quad (14)$$

Where U2 and V2 are the orthogonal matrixes of the watermark image and S2 is the diagonal matrix with the higher entries of the watermark image

6) Subtract the singular value of the decomposed original image form the singular value of the watermarked image and divide the values by the scaling factor α to obtain the singular value of the watermark image. This is given in (15)

$$S_5 = (S_4 - S_1)/a \quad (15)$$

7) Combining the singular values of the watermark image using the S5 (which was obtained in step 6) instead of S2 gives the extracted watermark image as given in (16).

$$W_2 = U_2 S_5 V_2^T \quad (16)$$

Where W2 is the extracted watermark image

IV. PERFORMANCE EVALUATION

In order to evaluate the performance of the proposed scheme, imperceptibility is chosen as the evaluation metrics. Watermarking algorithms are usually evaluated with respect to robustness and imperceptibility [13].

Imperceptibility

Imperceptibility is the measure of the quality of the watermarked image. The original image should not be distorted by the presence of the watermark or any kinds of attack [14]. These attacks may include some signal processing operations such as blurring, Gaussian noise, cropping, rotations, salt & pepper noise, contrast adjustment, sharpening, and histogram equalization [15].

To measure the imperceptible capability the peak signal to noise ratio (PSNR) can be used to measure the degradation caused by the watermarked effect [16]. The PSNR, which is measured in decibels, defines the resemblance between an original image and the reconstructed image. The higher the PSNR values of the reconstructed image the closer the resemblance of the reconstructed image to the original image [17].

The PSNR in decibels (dB) of the original image I(s) and the watermarked image W(s) can be calculated using (13)

$$PSNR_{dB} = 10\log\left(\frac{\text{MAX}^2}{MSE}\right) \quad (13)$$

Log is logarithm base 10. MAX is the maximum possible pixel value of the image and MSE is the mean square error [16]. MAX for a gray scale image with eight bits per pixel is 255. The MSE is the average of the pixel difference between two images [17]. The MSE can be defined as given in (14) below.

$$MSE = \frac{1}{S}\sum_{1}^{s}\left(I(s) - W(s)\right)^2 \qquad (14)$$

Where I(s) is the original image before watermarking and W(s) is the watermarked image.

V. EXPERIMENTAL RESULTS

Several experiments were conducted using a grey scale-level image "Barbara" and a "pepper" image. The "Barbara" and "pepper" images are used as the cover and the watermark image respectively. These images are shown in Fig 1-a and Fig 1-b below

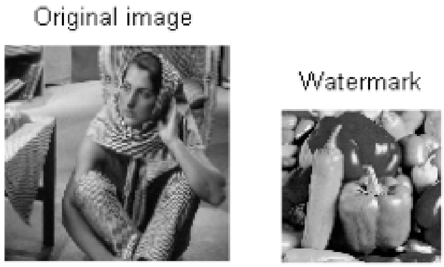

Fig 1-a: Original image Fig 1-b watermark image

The visual quality of the watermarked image for DD-DT-DWT-SVD watermarking technique is compared with that of the watermarked image of DWT-SVD watermarking technique by measuring the PSNR values of the Watermarked image for both algorithms. The watermarked image and their PSNR values for DWT-SVD algorithm and DD-DT-DWT-SVD algorithm is given in Fig 2.

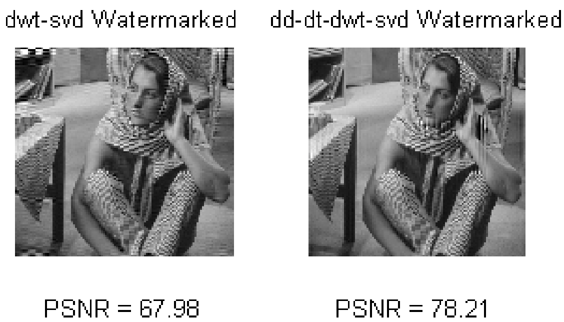

Fig 2 DWT-SVD and DD-DT-DWT-SVD Watermarked

It can be seen form Fig 2 that the PSNR value for DD-DT-DWT-SVD watermarking algorithm is higher than that of the DWT-SVD making DD-DT-DWT-SVD watermarking algorithm a better approach in term of visual quality perception.

In order to further test the imperceptibility of each algorithm, different kinds of attacks are applied to the watermarked images and the PSNR values of the attacked images are measured corresponding to the original images. The various attacks applied to the watermarked images are rotation, histogram equalization, salt & pepper noise, Gaussian noise, blurring, sharpening and contrast adjustment.

The PSNR values corresponding to various attacks on watermarked images are summarized in Table 1.

Table 1: PSNR and CC values for different types of attack for various algorithms

OPERATION		DWT-SVD	DD-DT-DWT-SVD
Watermarked		**56.25**	**74.21**
ATTACKS	Rotation 90°	29.95	30.65
	Rotation 180°	28.52	29.20
	Hist. Equalization	42.08	43.74
	Salt & pepper	37.53	39.09
	Gaussian noise	48.44	49.97
	Blurring	61.90	64.66
	Sharpening	47.32	54.45
	Contrast Adjustment	50.40	51.49

For proper representation, the images of the attacked watermarked images and their corresponding PSNR values for DWT-SVD are given in Fig 3-a and that for DD-DT-DWT-SVD are given in Fig. 3-b.

Data's in Table 1 and the figures in Fig 3-a and Fig 3-b shows that the DD-DT-DWT-SVD watermarking algorithm offers considerably higher PSNR values for almost all the signal processing operations as compared with DWT-SVD watermarking algorithms. Hence DD-DT-DWT-SVD watermarking algorithm is more imperceptible than DWT-SVD watermarking algorithms.

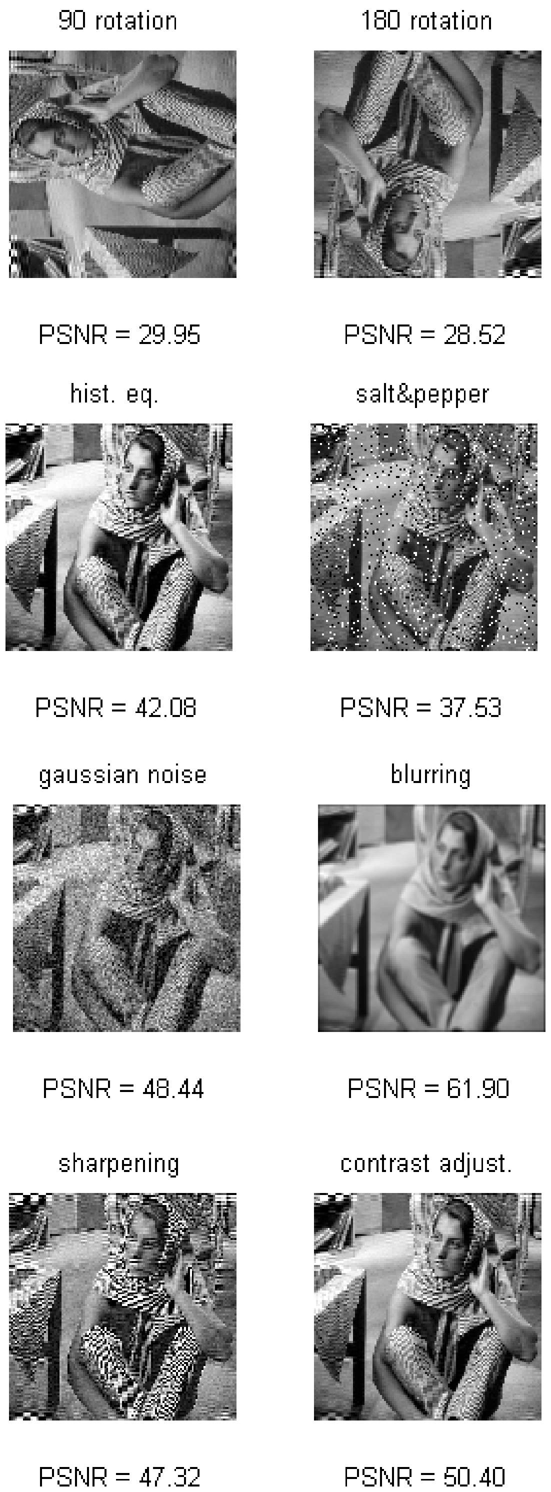

Fig. 3-a DWT-SVD attacked watermarked images and their PSNR values

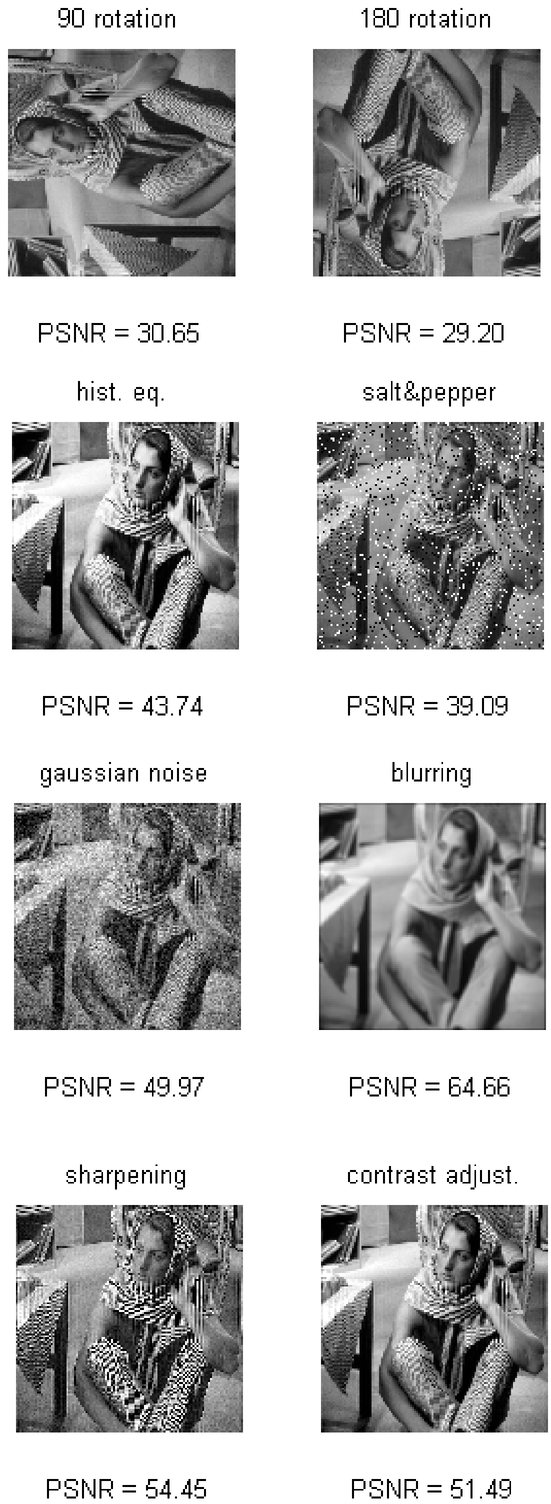

Fig. 3-b DD-DT-DWT-SVD attacked watermarked images and their PSNR values

VI. CONCLUSION

In this paper, a hybrid watermarking technique based on Double density Dual-Tree discrete Wavelet Transform and singular value decomposition has been presented. The experimental result shows that DD-DT-DWT-SVD provides better perceptibility in various signal processing operations as compared to DWT-SVD watermarking algorithms.

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