Digital Watermarking Based On Contourlet-SVD

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ABSTRACT:
In this paper, embedding a watermark image is performed in discrete Contourlet transform (CT) domain. It is known that the CT is able to capture the directional edges and contours superior to discrete wavelet transform. The proposed scheme is based on embedding watermark bits into the singular value of the selected blocks within low-pass sub-band of the original gray image CT. Two algorithms are implemented, the first uses adaptive quantization and the second uses quantization step. Our experimental results show that the method with quantization step has better fidelity in terms of peak signal to noise ratio (PSNR) and is more robust against geometrical and non-geometrical attacks in terms of normalized cross correlation (NC) in comparison with the first method, though, the method with adaptive quantization is blind in the sense not only quantization strategies but also, the original image is required.

1. INTRODUCTION

Digital watermarking is considered as an efficient tool to prove the ownership of digital data which is used in a wide variety of applications such as copyright protection, owner identification and medical applications [1]. Any watermarking system consists of two steps; embedding a watermark inside the host image and extracting the watermark at the receiver. In general, a watermark can be different types of data such as image, video, audio, and text. According to human visual system (HVS), a watermark is classified as either visible or invisible [2]. The main requirement of any watermarking system is robustness that means the ability to resist against different signal processing attacks such as filtering, cropping, geometric distortions and additive noise. Depending on the method used for extracting the watermark, systems named as blind, semi-blind and non-blind. Blind watermarking [3] does not require original image to extract the watermark whereas the non-blind watermarking [4] method extracts the watermark by comparing the watermarked image with the original image but semi-blind watermarking [5] method extracts the watermark by comparing the watermarked image with only the watermarked coefficients of original image. Embedding a watermark can be performed either in spatial or in transformed domain. Spatial domain watermarking methods are easy to implement but vulnerable to attacks [6]. Watermarking in transformed domain [7], such as discrete cosine, discrete Fourier, and discrete wavelet transforms, is done by manipulating the transformed coefficients values.

It was shown that image matrix singular value decomposition (SVD) reflects the internal image characteristics and it is stable under image processing. The hybrid discrete- cosine [8], Fourier [9], wavelet [4] and SVD proposed to improve the performance of watermarking scheme. The directionality of wavelet as a popular transform is limited to four directions. On the other words, discrete wavelet transform offers multistage and time-frequency localization of an image but it fails when image contains smooth contours in different directions. The Contourlet transform (CT) [10] possess multi-scale and time-frequency localization properties of wavelet in addition to directionality and anisotropy. Hybrid CT- SVD as a blind watermarking explained in [11] where, the watermark bits are embedded into the singular values in the SVD layers for the low-pass sub-band blocks in Contourlet domain with the quantization step, which ensures the transparency, and also achieves the highest possible robustness. Each low-pass sub-band block gives a singular value and the watermark bit is embed into the singular value.

In this paper, a watermarking scheme is presented in the CT domain. As the first method, a blind watermarking algorithm based on hybrid CT- SVD is

introduced. Then, as the second method, in order to improve the imperceptibility of the watermarked image and increase the robustness against geometrical and non-geometrical attacks, we embed watermark image in two steps and replace adaptive quantization step with quantization step. We show that the second method in comparison with the first method is more robust against geometrical and non-geometrical attacks such as salt & pepper noise, cropping, median filtering, Gaussian low-pass filter and Wiener filtering.

The paper is organized as follows: In Section 2, CT and SVD theory are explained briefly. Our proposed method based on hybrid CT-SVD for embedding a binary watermark image and extracting as well is given in Section 3. The simulation and experimental results are shown in Section 4. Concluding remarks are given in Section 5.

2. BACKGROUND
In this section, at first, we explain CT and then SVD for any two dimensional real signal.

2.1. Contour let Transform
In general, CT is a geometrical image based transform, so it efficiency represents image containing contours and texture [10]. The block diagram of CT is shown in Fig. 1. The main feature of this transform is its potential to capture the geometric smoothness of the contours. CT performs decomposition in two stages namely the Laplacian pyramid (LP), and directional filter bank (DFB) respectively. The LP is used to capture point discontinuities and it followed by DFB in order to link point discontinuities into linear. In general, the LP [13] is a method for achieving multi-scale decomposition. The function of LP at each step is to decompose an image to generate a sampled low-pass version of the original image where the difference between the original image and the prediction giving a band-pass image. One of the distinguishing features of LP is that each pyramid level generates only one band-pass image which does not have scrambled frequencies. DFB is used to process the band-pass image obtained from LP decomposition. DFB construction involves decomposing the input image and using diamond shaped filters. DFB effectively represents high frequency components of images, whereas low frequency components are handled poorly. DFB is implemented via a n-level tree structured decomposition that leads to 2^n sub-bands with wedge shaped frequency partitioning as shown in Fig. 2. As shown in Fig. 1, the first stage is LP decomposition and the second stage is DFB decomposition. In general, DFB is implemented by using quincunx filter bank with fan filters [10]. Fig. 2 shows the DFB via n-level tree structured decomposition that leads to $k = 2^n$ sub-band with wedge shaped frequency partitioning. Consider

Lena image with size 512×512. For LP decomposition $n = 2$ and the number of directional sub-bands at this successive level is $k = 4$. The corresponding coefficients belong to each level is shown in Fig. 3 where the top image contains the lowest frequency.

2.2. Singular Value Decomposition
Given A is a digital image with size $N \times N$, The SVD of real matrix A is

$$A = USV^T = \begin{pmatrix} u_{11} & \cdots & u_{1n} \\ \vdots & \ddots & \vdots \\ u_{n1} & \cdots & u_{nn} \end{pmatrix} \begin{pmatrix} \delta_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \delta_{nn} \end{pmatrix} \begin{pmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{n1} & \cdots & v_{nn} \end{pmatrix}^T \quad (1)$$

Where U and V are real unitary matrices, and S is a diagonal matrix with singular value entries and

$$\delta_{11} \geq \delta_{22} \geq \dots \geq \delta_{rr} = \dots = \delta_{nn} = 0 \quad (2)$$

It was shown that the singular values are less affected when the general signal processing is performed [11]. In this work, we use this feature of SVD in contour let transform for robust image watermarking.

3. WATERMARKING BY HYBRID CT_SVD
We propose a watermarking scheme using the hybrid CT-SVD. The scheme is robust against some attacks. The embedding and the extracting procedures are explained below in detail. In this paper, the original image is decomposed up to two levels $(n = 2)$, so the size of binary watermark is $(N/k, N/k)$, that means the original image (N), is divided by two for k times. Generally, all the methodologies for watermarking in Contourlet domain follow an additive approach to embed a watermark in a greatest energy sub-band. Given an original image, $f(x, y)$, with size $N \times N$, the energy is,

$$E_f = \frac{1}{N \times N} \sum_{x=1}^{N} \sum_{y=1}^{N} |f(x, y)|^2 \quad (3)$$

According to our experimental results, the low-pass sub-band image in CT has the greatest energy, and so it is suitable for embedding a watermark. In addition, in view of the robustness and invisibility, the low-pass sub-band is preferred
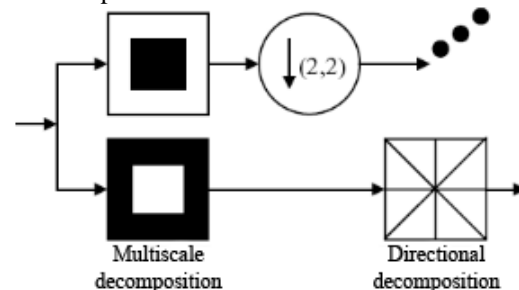

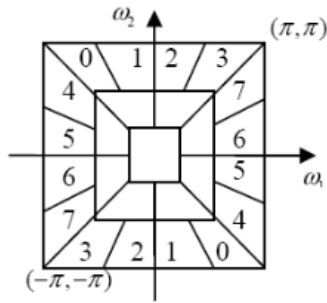**Fig. 1.** The block diagram of one level CT [12]

Fig. 2. Frequency partitioning ($n = 3$, $2^n = 8$)
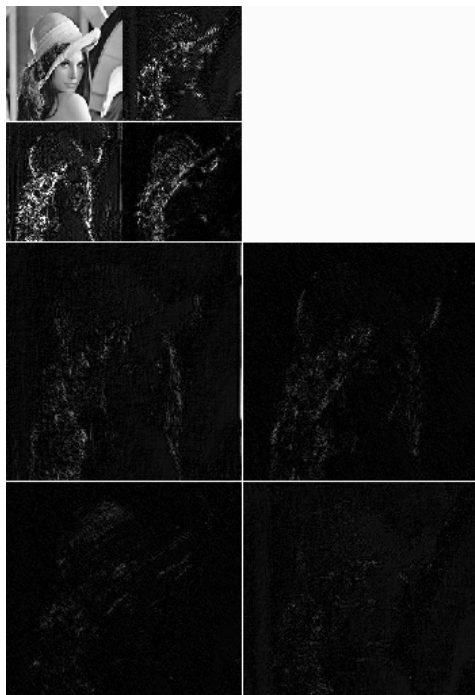
Wedge shaped frequency sub-bands [10].

Fig. 3. Contourlet decomposition coefficients of Lena as the test image

3.1. First Method
The embedding procedures are listed in following,

1. Consider block A_i and compute the adaptive quantization step value, δ_i,

$$\delta_i = \frac{\text{Floor}(\log_2 E_i \times 1000)}{1000} + \delta \tag{4}$$

Where the function Floor represents the round-off operation, and

$$E_i = \frac{1}{b \times b} \sum_{x=1}^{b} \sum_{y=1}^{b} |A_i(x,y)|^2 \tag{5}$$

is the energy value of each block, A_i; $i = 1,...,M$, M is the number of non-overlapped blocks, and δ is the quantization step.

2. Compute the SVD (Eq. (1)) of each block, A_i, and then

$$N_s^i = \left\| S^i \right\| + 1 \tag{6}$$

Where $\left\| . \right\|$ represents the Euclidean norm and S^i is a diagonal matrix with singular value entries. In Eq. (6), in order to avoid small values, we add the constant positive number equal one to $\left\| S^i \right\|$. Based on the obtained value, N_s^i, for each block, we have,

$$N^i = [\frac{N_s^i}{\delta_i}]_{i=1,...,M} \tag{7}$$

3. Embed each watermark bit by modifying integer number N_i,

$$N^i = \begin{cases} N^i + 1 & ; \ \{\text{mod}(N^i,2) = 1 \ \& \ w_i = 1\} \ \text{OR} \\ & \quad \{\text{mod}(N^i,2) = 0 \ \& \ w_i = 0\} \\ N^i & ; \ \text{O.W} \end{cases} \tag{8}$$

Where $\text{mod}(N^i,2)$ is one if the value of N_i is odd and $\text{mod}(N^i,2)$ is zero if the value of N_i is even.

4. Compute
$$N''^i = \delta_i \times N^i + \delta_i/2 \tag{9}$$
and the modified singular values, and the watermarked block, A_i'. Using the inverse CT constructs the watermarked image, f'.

Now, suppose the watermarked image is f'. For extracting the watermark, we decompose f' into Contourlet domain up to two level and obtain the low-pass sub-band, f_J'. The extracting procedure is listed in following,

1. Segment f_J' into non-overlapping blocks, named as A_i' with size $b \times b$.

2. Compute $N_s'^i = \left\| S'^i \right\| + 1$ where S'^i denotes a vector formed by the singular values of each block A_i' and quantize it by quantization step, δ_i, that is served as a secret key, according to

$$N'^i = [\frac{N_s'^i}{\delta_i}]_{i=1,2,...,M}$$

3. Extract the watermark bits,

$$w_i' = \begin{cases} 1 & ; \ \text{mod}(N'^i,2) = 0 \\ 0 & ; \ \text{mod}(N'^i,2) = 1 \end{cases} \tag{10}$$

3.2. Second Method
In second method, for improving the imperceptibility and robustness against geometrical and non-geometrical attacks, we embed watermark image in two

stages and replace adaptive quantization step δ_i with quantization step δ. The embedding procedure in first stage is,

1. Put the first L coefficients of low-pass sub-band with maximum energy values in a vector $S = \{s_1, s_2, ..., s_L\}$, and the watermark bits in $W = \{w_1, w_2, ..., w_L\}$.

2. Embed the watermark bits into the selected Contourlet coefficients [4],

$$\hat{s}_i = s_i + \alpha\, s_i\, w_i \tag{11}$$

Where $\hat{s}_i$ is the modified or watermarked coefficient, w_i is the watermark bits, s_i is the original selected coefficient, and α is an adopted parameter which controls imperceptibility and robustness of the watermarked image. After manipulating the selected coefficients, they are inserted back at the same location where they had been taken from. The inverse CT is performed and the watermarked image (f_0) is obtained.

At the second stage, the watermarked image (f_0) is decomposed up to two levels with CT transform. According to Eq. (3), the low-pass sub-band image, f_J, is chosen for embedding the watermark, w. The embedding procedure in second stage is exactly the same as what is described for the first method. For this purpose, we segment the f_J into non-overlapping blocks, A_i with size 4×4. We construct the watermarked image, f_J', from all the watermarked blocks and then f_0' by using the inverse CT.

As the extracting procedure for implementing the second method is the same as the first method, we refuse to explain it again.

4. SIMULATION RESULTS

In this paper, two error metrics, normalized cross correlation (NC) and peak signal to noise ratio (PSNR), are used to evaluate the proposed algorithm. For the host image $f(i, j)$ and the watermarked image,

(a)   (b)

(c)   (d)

(e)   (f)
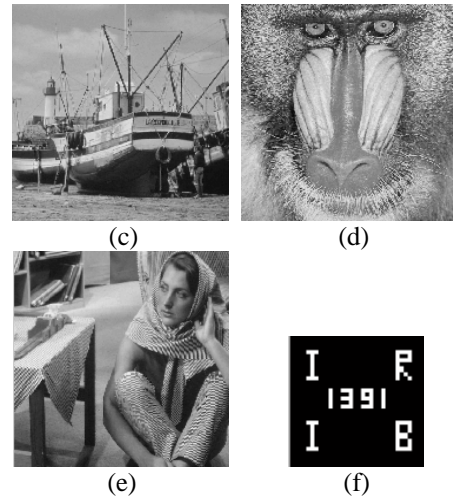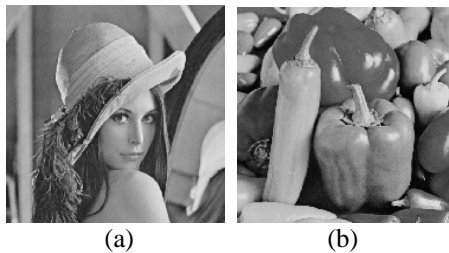
Fig. 4. (a-e) the original test images, in order, Lena, Peppers, Boat, Baboon, Barbara, with size 512×512, and (f) the binary watermark image with size 32×32

$\hat{f}(i, j)$, with sizes $N \times N$, the PSNR measures the image fidelity and it is computed in dB as,

$$PSNR = 10\log\left(\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(\hat{f}(i, j))^2}{\sum_{i=1}^{N}\sum_{j=1}^{N}(f(i, j) - \hat{f}(i, j))^2} \right) \tag{12}$$

And NC is

$$NC = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i, j) - w_{mean})(\hat{w}(i, j) - \hat{w}_{mean})}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i, j) - w_{mean})^2 \sum_{i=1}^{N}\sum_{j=1}^{N}(\hat{w}(i, j) - \hat{w}_{mean})^2}} \tag{13}$$

Where $w(i, j)$ and $\hat{w}(i, j)$ denote the original and the extracted watermark, w_{mean} and $\hat{w}_{mean}$ are mean value of the original and the extracted watermark image. Five host images with size 512×512, Fig. 4(a-e), and a binary watermark logo with size 32×32, Fig. 4(f), are used in this work. According to our experimental results, the best values for parameters δ, δ_i and α are 45, 193 and 0.001 respectively. Both LP and DFB are implemented by 'pkva' filters, because of its better efficiency [8]. The number of decomposition level is considered to be two. The watermarked images by using the two proposed method are shown in Fig. 5. The achieved PSNRs of the first method are [30.09, 30.62, 29.82, 30.55, 30.51] and the achieved PSNR's of the second method are [41.2, 40.56, 40.56, 40.85, 41.16] in order. So, the second described algorithm in Section 3 has better imperceptibility in comparison with the first method. In addition, our experimental results show that the second method is also more robust against geometrical and non-geometrical attacks such

as salt & pepper noise, median filtering, Gaussian low-pass filter, cropping and Wiener filtering. This fact is shown in Fig. 6 and Table 1, where Lena is used as the host image and a binary logo used as watermark.

5. CONCLUSION
In this paper, two watermarking scheme are presented by using the Contour let decomposition. The original gray scale image is decomposed by CT up to two levels and the watermark bits are embedded into the singular values of the selected blocks belong to the low-pass sub-band. Two different approaches are proposed. The first method with adaptive quantization step has less fidelity. For increasing the imperceptibility and achieving more robustness against geometrical and non-geometrical attacks, the second method is replaced with quantization step.
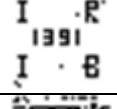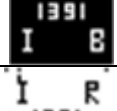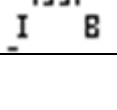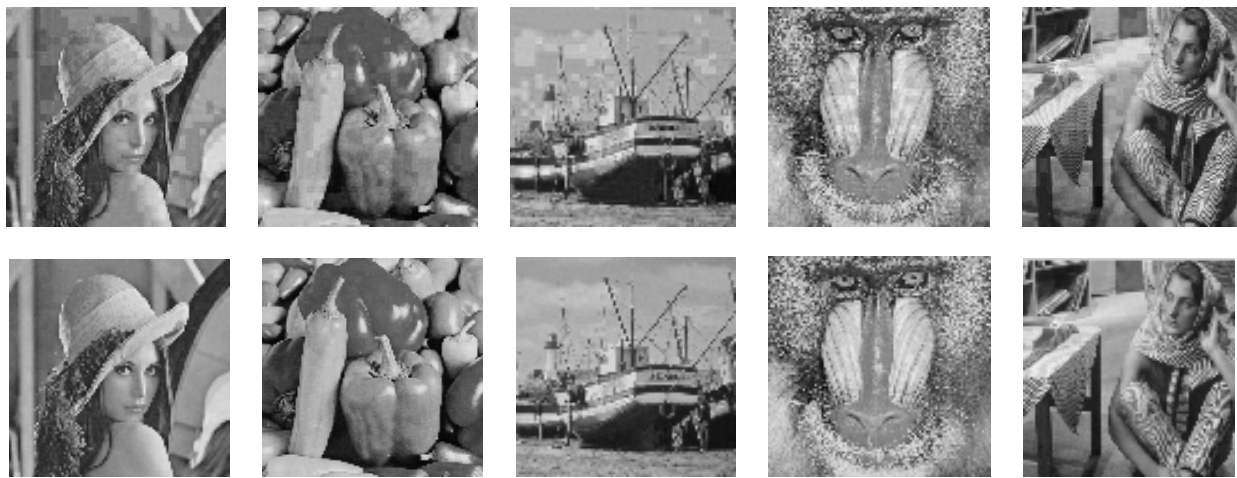

Fig. 5. Watermarked test images by implementing the first method (top-first row) and the second method (bottom-second row) which are explained in Section 3

Fig. 6. Attacking the watermarked Lena image from left to right in order, salt & pepper noise, median filtering, Wiener filter, Gaussian low-pass filter, and cropping, where the top-first row images belong to the first method and the bottom-second row images belong to the second method

Table 1. Shown the extracted watermark, computed PSNR, and obtained NC for the attacked watermarked Lena image

Attacks	Extracted watermark		PSNR		NC	
	First Method	Second Method	First Method	Second Method	First Method	Second Method
Salt & pepper noise density=0.001			5.63	5.37	0.99	0.98
Median filter window size 3×3			24.1	34.19	0	0.7
Gaussian filter window size 3×3			24	31.51	0.1	0.8
Wiener filter window size 3×3			27.97	35.86	1	1
Cropping (0.12%)			24.04	22.23	0	0.94

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