

Using Contourlet Transform and Discrete Cosine Transform and SVD for Digital Watermarking

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Abstract

In this paper, embedding a watermark in the 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. We introduce three methods. The first proposed method 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 and uses adaptive quantization. The second method uses quantization step, are implemented. Our experimental results show that the second 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 only quantization strategies but not the original image is required. The third proposed method is based on embedding watermark bits into the selected blocks within last sub-band of first level of the original gray image CT. This method is semi-blind and our experimental results show that robustness against geometrical and non-geometrical attacks in terms of normalized cross correlation (NC) is better than two previous methods and third method robust against too many attacks type.

Keywords: Digital image watermarking, Contourlet transform, discrete Cosine transform, geometric and non-geometric attacks, singular value decomposition, quantization strategies.

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 need the 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. 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 transform (DCT), discrete Fourier transform (DFT), and discrete wavelet transform (DWT), is done by manipulating the transformed coefficients values. In particular, DCT is a Fourier-related transform but using only real numbers. DCTs are equivalent to DFTs of roughly twice the length, operating on real data with even symmetry (since the Fourier transform of a real and even function is real and even), where in some variants the input and/or output data are shifted by half a sample. The directionality of DWT as a popular transform is limited to four directions. On the other words, DWT offers multistage and time-frequency localization of an image but it fails when image contains smooth contours in different directions. The CT possess multi-scale and time-frequency localization properties of wavelet in addition to directionality and anisotropy. It was shown that singular value decomposition (SVD) [6] reflects the internal image characteristics and it is stable under image processing. The hybrid DCT [6], DFT [7], DWT [4] and CT [8] proposed to improve the performance of digital watermarking. Hybrid CT- SVD as a blind watermarking was proposed 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.

In this paper, three watermarking methods in the CT domain is presented. In the first method, a blind watermarking algorithm based on hybrid CT- DCT- 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. In third method, a semi-blind watermarking algorithm based on hybrid CT-

DCT is introduced. We combined CT with DCT to provide the embedded watermark higher imperceptibility yet more energy. We show that the third method is robust against many attacks than two previous methods and too is more robust against geometrical and non-geometrical attacks such as salt & pepper noise, median filtering, wiener filter, Gaussian low-pass filter, cropping , Gaussian noise, Laplacian removal, histogram equalization, grey scale inversion, gamma correction and scaling.

The paper is organized as follows: In Section 2, CT, DCT and SVD theory are explained briefly. Our proposed methods based on hybrid CT-DCT-SVD and CT-DCT 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, we briefly explain CT, DCT and SVD in order to process any two dimensional real signal or equivalently an image.

2.1 Contourlet Transform (CT)

The CT is a new image decomposition scheme, which provides the flexible multi-resolution representation for two dimension signals [8]. The two properties that make CT superior to other transforms such as wavelet are directionality and anisotropy [8]. The block diagram of CT for one level decomposition is shown in Fig. 1 which includes two sub-blocks, laplacian pyramid (LP) [9] and directional filter bank (DFB) [12]. 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. So, the output of LP at each level includes the sampled low-pass and the band- pass version of the input signal. The band-pass image is then processed by the DFB. 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. Fig. 2 shows the DFB via n -level tree structured decomposition that leads to $k = 2^n$ sub-band with wedge shaped frequency partitioning. In general, LP decomposes the input image into the low-pass and band-pass image, then, DFB decomposes the band-pass image in order to capture the directional information. The same above procedures are repeated on the low-pass image at the second level of CT. Combination of LP and DFB gives a double filter bank structure known as Contourlet filter bank. The Contourlet filter bank decomposes the given image into directional multi-bands at multiple scales. In general, DFB is implemented by using quincunx filter bank with fan filters [8]. Now, consider Lena image with size 512×512 . For LP decomposition $n=2$ and the number of directional sub-bands at last 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.

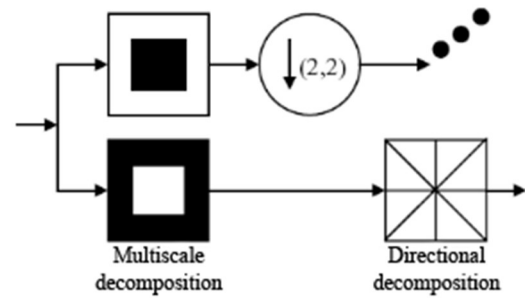


Fig. 1 The block diagram of one level CT [12].

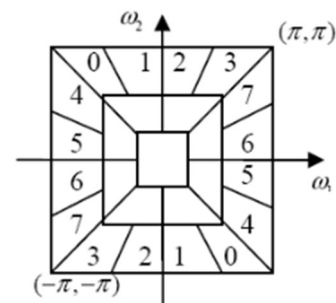


Fig. 2 Frequency partitioning ($n=3$, $2^n=8$). Wedge shaped frequency sub-bands [10].

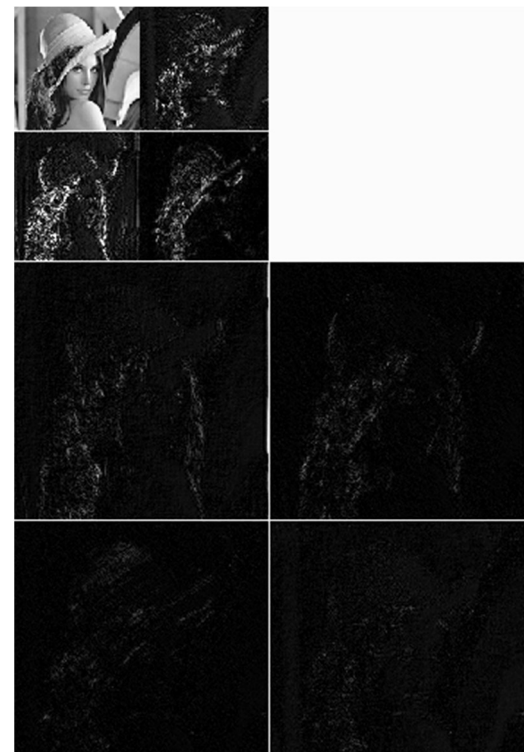


Fig. 3 Contourlet decomposition coefficients of Lena as the test image.

2.2 Discrete Cosine Transform (DCT)

The DCT is a technique for converting a signal into elementary frequency components [10]. It represents an image as a sum of sinusoids of varying magnitudes and frequencies. Suppose an input image, A , with $M \times N$

pixels. The DCT coefficients, $\beta_{p,q}$, for the transformed output image, B , are computed as,

$$\beta_{p,q} = \alpha_p \alpha_q \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} A_{m,n} \cos \frac{\pi(2m+1)p}{2M} \cos \frac{\pi(2n+1)q}{2N} \quad (1)$$

where $A_{m,n}$ is pixel intensity of the input image, and

$$\alpha_p = \begin{cases} 1/\sqrt{M} & p = 0 \\ \sqrt{2/M} & 1 \leq p \leq M-1 \end{cases} \quad (2)$$

$$\alpha_q = \begin{cases} 1/\sqrt{N} & q = 0 \\ \sqrt{2/N} & 1 \leq q \leq N-1 \end{cases} \quad (3)$$

Obviously, the transformed output image, B , has the same size with the input image, i.e. $0 \leq p \leq M-1$,

$0 \leq q \leq N-1$. Using the DCT coefficients, the original image can be reconstructed by applying the inverse DCT as,

$$A_{m,n} = \sum_{p=0}^{M-1} \sum_{q=0}^{N-1} \alpha_p \alpha_q \beta_{p,q} \cos \frac{\pi(2m+1)p}{2M} \cos \frac{\pi(2n+1)q}{2N} \quad (4)$$

where $0 \leq m \leq M-1$ and $0 \leq n \leq N-1$. The popular block-based DCT segments an image into non-overlapping blocks and applies DCT for each block. As a result, there are three frequency sub-bands; low, middle, and high. In general, DCT-based watermarking is based on two facts, the most signal energy lies at low-frequencies sub-band which contains the most important visual parts of an image and high frequency components of an image are usually removed through compression and noise attacks. Therefore, modifying the middle frequency sub-band generates the watermarked image with appropriate imperceptibility and robust to attacks [11]- [15].

2.3 Singular Value Decomposition (SVD)

Given A is a digital image with size $N \times N$, The SVD of real matrix A is,

$$A = USV^T = \begin{pmatrix} u_{11} & \dots & u_{1n} \\ \vdots & \ddots & \vdots \\ u_{n1} & \dots & u_{nn} \end{pmatrix} \begin{pmatrix} \delta_{11} & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & \delta_{nn} \end{pmatrix} \begin{pmatrix} v_{11} & \dots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{n1} & \dots & v_{nn} \end{pmatrix}^T \quad (5)$$

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

$$\delta_{11} \geq \delta_{22} \geq \dots \geq \delta_{rr} = \dots = \delta_{nn} = 0 \quad (6)$$

It was shown that the singular values are less affected when the general signal processing is performed [16]. In this work, we use this feature of SVD in hybrid CT- DCT for robust image watermarking.

3. Our Proposed Method Based on CT, DCT and SVD

We propose three watermarking methods based on hybrid CT- DCT and SVD. Original image is decomposed up to two levels ($n=2$). 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,

$$E_f = \frac{1}{N \times N} \sum_{x=1}^N \sum_{y=1}^N |f(x,y)|^2 \quad (7)$$

According to our experimental results, the low-pass sub-band and the last directional sub-band of each level in CT have the greatest energy, and so they are suitable for embedding a watermark. The low-pass sub-band is suitable because of invisibility property and the last directional sub-band is suitable because of robustness property.

3.1 First Method

The embedding procedures are listed in following,

1. Decompose the original image by CT up to two levels ($n=2$). The low-pass sub-band is used for block based DCT, where each block, A_i , has the size of $b \times b$.
2. Compute the adaptive quantization step value, δ_i , for each block,

$$\delta_i = \frac{\text{Floor}(\log_2 E_i \times 1000)}{1000} + \delta \quad (8)$$

where function Floor represents the round-off operation, and E_i is the energy value of each block, A_i ; $i=1, \dots, M$, M is the number of non-overlapped blocks, and δ is the quantization step.

3. Compute SVD by using Eq. (5) of each block, A_i , and then

$$N_s^i = \|S^i\| + 1 \quad (9)$$

where $\|\cdot\|$ represents the Euclidean norm and S^i is a vector formed by the singular values of each block. Based on the obtained value, N_s^i , for each block, we have,

$$N^i = \left\lfloor \frac{N_s^i}{\delta_i} \right\rfloor_{i=1, \dots, M} \quad (10)$$

4. Suppose watermark image bits, $W = \{w_1, w_2, \dots, w_L\}$ and embed each bit of the watermark image into each block by modifying the integer number N_i as,

$$N^i = \begin{cases} N^i + 1 & ; \{\text{mod}(N^i, 2) = 1 \ \& \ w_i = 1\} \text{ OR} \\ & \{\text{mod}(N^i, 2) = 0 \ \& \ w_i = 0\} \\ N^i & ; \text{O.W} \end{cases} \quad (11)$$

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. Then, by using $\hat{N}^i = \delta_i \times N^i + \delta_i / 2$, the modified singular values and the watermarked block, \hat{A}_i are obtained. Using the inverse DCT and then inverse CT constructs the watermarked image, \hat{f} .

Now, suppose the watermarked image is \hat{f} . For extracting the watermark, we decompose \hat{f} into Contourlet domain up to two levels and obtain the low-pass sub-band, \hat{f}_J and apply DCT to this sub-band and create non-overlapping blocks \hat{A}_i with size $b \times b$. The extracting procedure is listed in following,

1. Compute $\hat{N}_s^i = \|\hat{S}^i\| + 1$ where \hat{S}^i denotes a vector formed by the singular values of each block \hat{A}_i . Then, obtain $\hat{N}^i = [\frac{\hat{N}_s^i}{\delta_i}]_{i=1,2,\dots,M}$ where the quantization step, δ_i , is served as a secret key.
2. Extract the watermark bits,

$$\hat{w}_i = \begin{cases} 1 & ; \quad \text{mod}(\hat{N}^i, 2) = 0 \\ 0 & ; \quad \text{mod}(\hat{N}^i, 2) = 1 \end{cases} \quad (12)$$

3.2 Second Method

In order to improve the imperceptibility and robustness, the image watermarking is performed in two stages. The embedding procedure at the first stage is,

1. Decompose the original image by CT up to two levels ($n = 2$).
2. Put the first L coefficients of low-pass sub-band with maximum energy values in a vector $X = \{x_1, x_2, \dots, x_L\}$, and the watermark bits in $W = \{w_1, w_2, \dots, w_L\}$.
3. Embed the watermark bits into the selected Contourlet coefficients [4],

$$\hat{X}_i = X_i + X_i \lambda w_i \quad (13)$$

where \hat{X}_i is the modified or watermarked coefficient, w_i is the watermark bits, X_i is the original selected coefficient, and λ is an adopted parameter which controls imperceptibility and robustness of the watermarked image. After manipulating the selected coefficients, they are relocated where they had been taken from. The inverse CT is performed and the watermarked image is obtained.

At the second stage, the watermarked image is considered as original and a watermark bits embed according to the first method which explained in Section 3.1. Extracting the watermark is the same as the first method, so, we refuse to explain it again.

3.3 Third Method

The embedding procedures are listed in following,

1. Decompose the original image by CT up to two levels. As, the low-pass sub-band and the last directional sub-band of each level in CT have the greatest energy, in view of the more robustness and invisibility than two previous methods and balance between this two factor, the last directional sub-band in each level, particular

the last level is preferred. We choose last (third) sub-band of first level, in CT transform.

2. The chosen sub-bands are used for block based DCT, where each block, A_i , has the size of $b \times b$, $i = 1, 2, \dots, M$ and M is the number blocks.
3. Compute the energy, E_i , and the mean value energy, \bar{E}_i , of each block, and embed the watermark bits into the first coefficient of each block as follows:

$$\hat{X}_i(1,1) = X_i(1,1) + \alpha w_i \quad \text{if} \quad E_i + \beta > \bar{E}_i \quad (14)$$

OR $E_i + \beta < \bar{E}_i$

where $\hat{X}_i(1,1)$ is the modified or watermarked coefficient, w_i is the watermark bit, $X_i(1,1)$ is the original selected coefficient, α is an adopted parameter which controls imperceptibility and robustness and β is a pre-determined threshold. After manipulating the selected coefficients, they are relocated where they had been taken from. We apply inverse DCT from all the watermarked blocks and then inverse CT is performed and the watermarked image (\hat{f}) is obtained.

Now, suppose the watermarked image is \hat{f} . For extracting the watermark, we decompose \hat{f} into Contourlet domain up to two levels and obtain the third sub-band of first level (\hat{f}_J) and apply DCT to this sub-band and create non-overlapping blocks \hat{A}_i with size $b \times b$. We compute the energy, \hat{E}_i , and the mean value energy, $\bar{\hat{E}}_i$, of each block, then, the watermark bit from the selected coefficient of each block is extracted as follows:

$$\hat{w}_i = \frac{(\hat{X}_i(1,1) - X_i(1,1))}{\alpha} \quad (15)$$

if $\hat{E}_i + \beta > \bar{\hat{E}}_i$ OR $\hat{E}_i + \beta < \bar{\hat{E}}_i$

where $\hat{X}_i(1,1)$ is the modified or watermarked coefficient, \hat{w}_i is the extracted watermark bit, $X_i(1,1)$ is the original selected coefficient and α and β are same value that we use in embedding step.

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

$$PSNR = 10 \log \left(\frac{\sum_{i=1}^N \sum_{j=1}^N (\hat{f}(i, j))^2}{\sum_{i=1}^N \sum_{j=1}^N (f(i, j) - \hat{f}(i, j))^2} \right) \quad (16)$$

and NC is

$$NC = \frac{\sum_{i=1}^N \sum_{j=1}^N (w(i, j) - w_{mean})(\hat{w}(i, j) - \hat{w}_{mean})}{\sqrt{\sum_{i=1}^N \sum_{j=1}^N (w(i, j) - w_{mean})^2 \sum_{i=1}^N \sum_{j=1}^N (\hat{w}(i, j) - \hat{w}_{mean})^2}} \quad (17)$$

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. In this work, five host images, Fig. 4(a-j), images with size 512×512 , and a binary watermark logo, Fig. 4(k), with size 32×32 are used. According to our experimental results, the best values for parameters δ , δ_i , λ , α and β in order are 45, 193, 0.001, 100 and 1000. The number of decomposition level in CT is considered to be two. Both LP and DFB are implemented by 'pkva' filters [8]. We segment the chosen sub-bands into blocks with size 4×4 . The watermarked images by using the three methods are shown in Fig. 5. The achieved PSNR's of the first method are [30.09, 30.62, 29.82, 30.55, 30.51, 39.06, 40.34, 39.85, 40.43, 39.11] and

the achieved PSNR's of the second method are [41.2, 40.56, 40.56, 40.85, 41.16, 40.4, 42.16, 41.12, 41.25, 40.17] in order. The achieved PSNRs of third method are [37.16, 37.73, 37.63, 37.73, 35.59, 37.95, 37.42, 37.83, 37.14, 37.63] in order which is preferred to the two previous methods. The PSNR results from three methods is shown in Fig.6. In addition, our experimental results show that third method is robust against geometrical and non-geometrical attacks such as salt & pepper noise, median filtering, wiener filter, Gaussian low-pass filter, cropping, Gaussian noise, Laplacian removal, histogram equalization, grey scale inversion, gamma correction and scaling. This fact is shown in Table (1) and Fig. 7-8, where Lena is used as the host image and binary logo, w , used as watermark.

The method [16] is also a blind watermarking technique based on CT- SVD. A total of 1024 watermark bit are embedded in Lena by using SVD. PSNR reported is 43.5 dB and the number of attacks reported are only 5. Watermark image can survive to many attacks in our method compared to [16]. This comparison between these three methods is shown in Table (2).

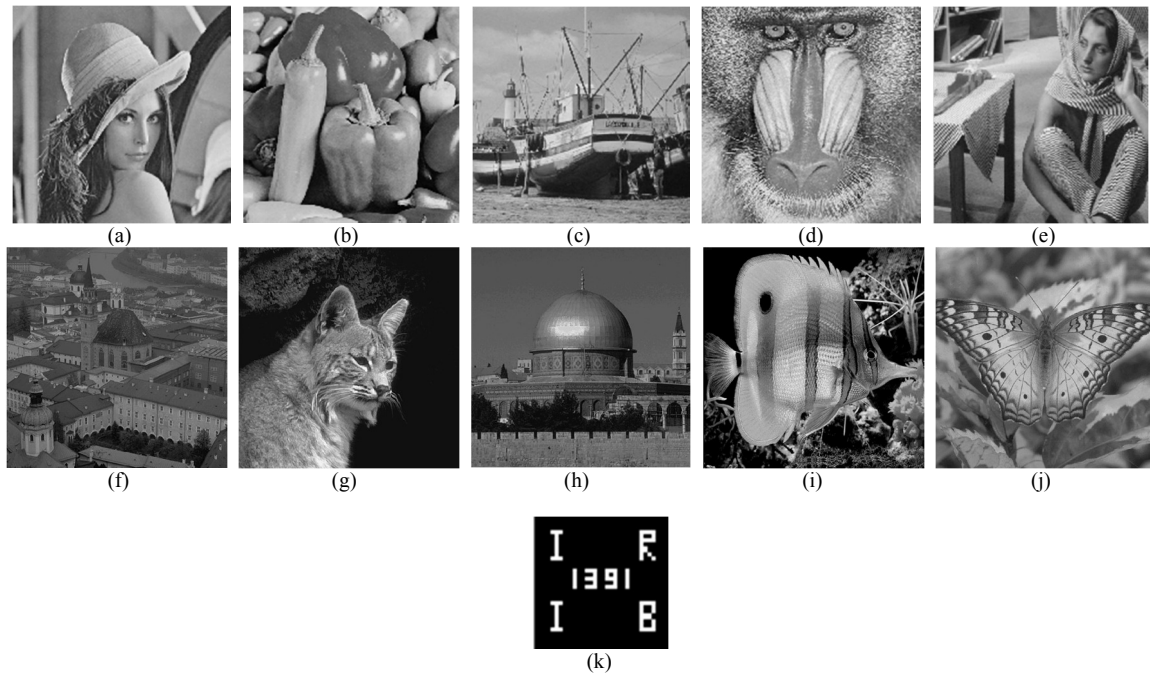


Fig. 4 (a-j) the original test images, in order, Lena, Peppers, Boat, Baboon, Barbara, with size 512×512 , and (k) the binary watermark image with size 32×32 .





Fig. 5 Watermarked test images by implementing: the first method (one and second rows), the second method (third and fourth rows) and third method (fifth and sixth rows) which are explained in Section 3.

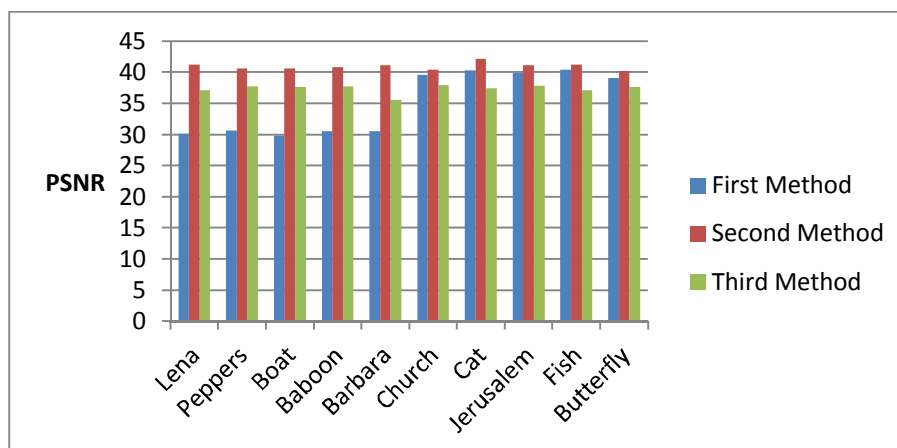







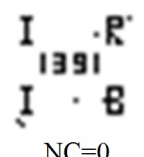





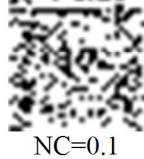

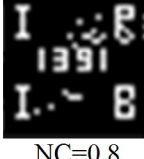



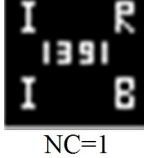

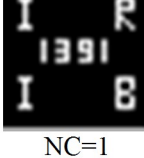



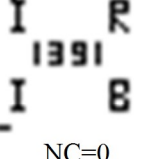

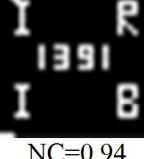









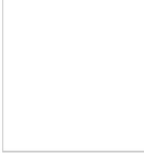







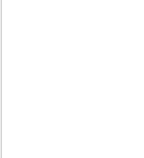


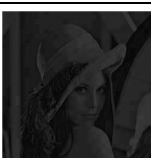

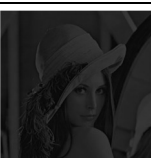

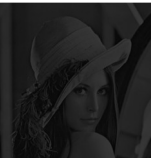







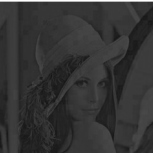







Fig. 6 Computed PSNR for test images in three methods.

Table 1: Shown the extracted watermark, computed PSNR, and obtained NC for the attacked watermarked Lena image in three methods

Attacks	First Approach		Second Approach		Third Approach	
	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark	Watermarked Image	Extracted Watermark
Salt & Pepper noise, density=0.01	 PSNR=21.63	 NC=0.99	 PSNR=21.37	 NC=0.98	 PSNR=30.37	 NC=1
Median filter, window size: 3×3	 PSNR=24.1	 NC=0	 PSNR=34.19	 NC=0.7	 PSNR=25.09	 NC=0.9997
Gaussian filter, window size: 3×3	 PSNR=24	 NC=0.1	 PSNR=31.51	 NC=0.8	 PSNR=31.87	 NC=1
Wiener filter, window size: 3×3	 PSNR=27.97	 NC=1	 PSNR=35.86	 NC=1	 PSNR=36.65	 NC=0.998
Cropping, (0.12%)	 PSNR=24.04	 NC=0	 PSNR=22.23	 NC=0.94	 PSNR=21.9	 NC=0.98
Gaussian noise, density=0.01	 PSNR= 5.36	 NC=0.3	 PSNR:7.31	 NC: 0.12	 PSNR=25.36	 NC=1
Laplacian removal	 PSNR=5.31	 NC=0.29	 PSNR: 5.31	 NC: 0.29	 PSNR=5.31	 NC=1
Grey scale inversion	 PSNR= 5.37	 NC=0.29	 PSNR: 5.37	 NC: 0.29	 PSNR=5.37	 NC=1
Scaling, (0.25)	 PSNR= 7.82	 NC=0.15	 PSNR: 7.84	 NC: 0.23	 PSNR=17.8	 NC=1

Histogram equalization	 PSNR=5.37	 NC=0.19	 PSNR: 5.37	 NC: 0.18	 PSNR=20.37	 NC=1
Gamma correction, (5)	 PSNR= 9.53	 NC=0.19	 PSNR: 41.19	 NC: 0.41	 PSNR=16.2	 NC=0.681

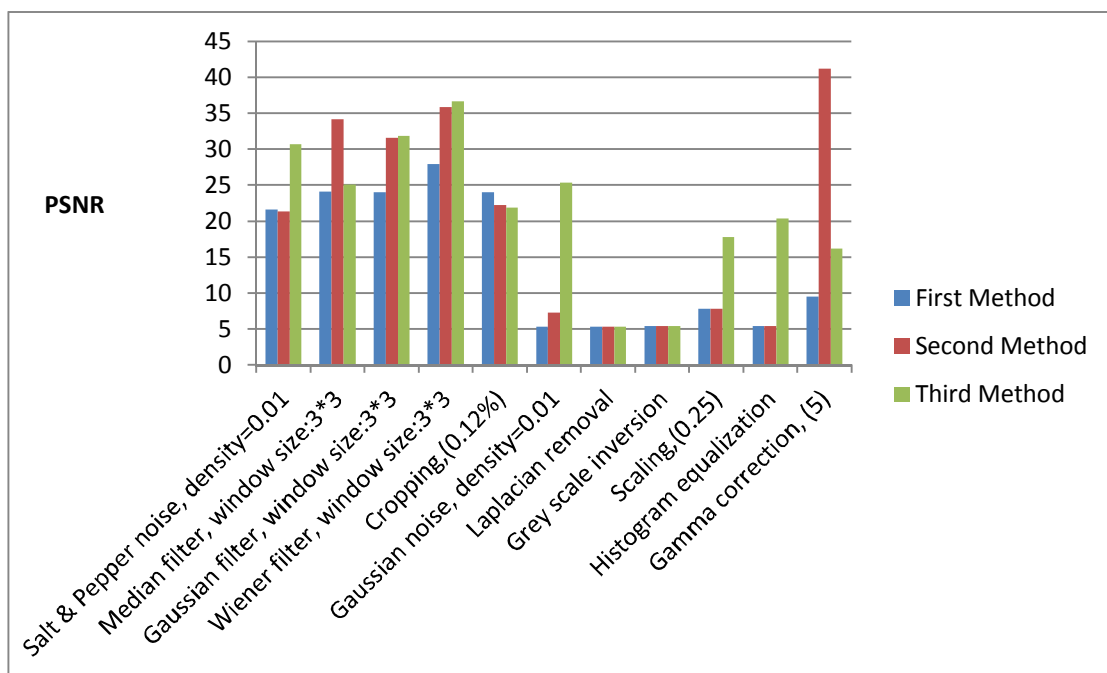


Fig. 7 Computed PSNR from the attacked watermarked Lena image in three methods.

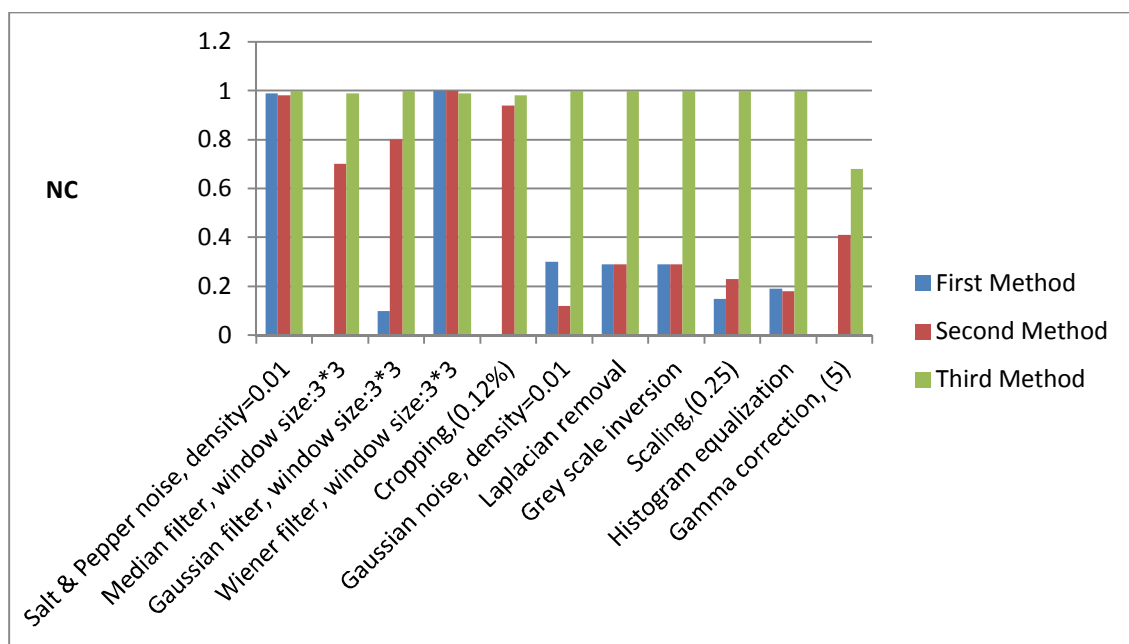


Fig. 8 Computed NC from the attacked watermarked Lena image in three methods.

Table 2: Comparison of our methods with [16] based lena image

Characteristic	First Method	Second Method	Third Method	[16]
No of Watermark Bits Embedded	1024	1024	1024	1024
PSNR in dB	30.09	41.2	37.16	43.5
No of Attacks Reported	11	11	11	5
Watermark Embedding Position	In DCT blocks	In DCT blocks & Low-pass sub-band	In DCT blocks	In DCT blocks
Watermark Embedding Procedure	Using CT transform, DCT & SVD	Using CT transform, DCT & SVD	Using CT transform, DCT	Using CT transform & SVD

5. Conclusions

In this paper, three watermarking methods by using the Contourlet decomposition, DCT and SVD are presented. The original gray scale image is decomposed by CT up to two levels, then low-pass sub-band in first and second method and last (third) sub-band of first level in third method are obtained and DCT is applied to it. The watermark bits are embedded into the each block of this sub-band. In first scheme, 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 with quantization step is replaced. For increasing to achieve more robustness against too many attacks, we proposed third method that use a control factor and threshold factor in energy level.

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