Robust Digital Watermarking Scheme using Contourlet Transform

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Summary
A novel oblivious and highly robust watermarking scheme using Multiple Descriptions (MD) and Quantization Index Modulation (QIM) of the host image is presented in this paper. The watermark is embedded in the Discrete Contourlet Transform domain (CT). Discrete Countourlet Transform (CT) is able to capture the directional edges and contours superior to Discrete Wavelet Transform (DWT). Watermark embedding is done at two stages for achieving robustness to various attacks. This algorithm is highly robust for different attacks on the watermarked image and superior in terms of Peak Signal to Noise Ratio (PSNR) and Normalized Cross correlation (NC).
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Key words:
Digital image watermarking, Contourlet Transform, Multiple description coding, dither quantization.

1. Introduction

A major issue of digital multimedia data exchange over the internet is data authentication. Image attacks either intentional or unintentional try to remove ownership information (such as logo). Image watermarking algorithms using Discrete Cosine Transform (DCT) [1, 2], Discrete Wavelet Transform (DWT) [3, 4], Discrete Hadamard Transform (DHT) [5] and Singular Value Decomposition (SVD) [6, 7] are available in the literature. The basic philosophy in majority of the transform domain watermarking schemes is to modify the transform coefficients based on the bits of watermark image. Even though, DWT is a popular, powerful and familiar to watermarking community, it has its own limitations in capturing the directional information such as smooth contours, and directional edges of the image. This problem is addressed by Discrete Contourlet Transform (CT) proposed by Do et al., [8]. CT is capable of capturing the directional information in addition to multi resolution, localization, and critical sampling characteristics. In oblivious (blind or public) watermarking scheme, the presence of the host image is not required in retrieving the watermark image. In non-oblivious watermarking schemes, the presence of the host image and/or watermark image is required. This paper presents a highly robust and oblivious (blind) watermarking scheme in the CT domain. Superiority of the proposed method is observed over Wang et al.'s method, which is a DCT based scheme in terms of number of attacks, that can withstand and giving improved PSNR.

This paper is organized as follows: In Section 2, Multiple Description Coding (MDC) is presented. Contourlet transform is discussed in Section 3. QIM is discussed in brief in Section 4. Details of the proposed image watermark embedding technique and extraction process are given in Section 5. Experimental results are discussed in Section 6. Concluding remarks are given in Section 7..

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2. Multiple Description Coding

Source information is partitioned into Multiple Descriptions Coding (MDC), viz., odd and even pixel intensities (two descriptions) of host image. The receiver is able to reconstruct the original source within some prescribed distortion levels by using few of the descriptions. This concept of MDC can be adapted to digital image watermarking as suggested by Chandramouli et al., [9]. Information content of the host image is decomposed into two descriptions. These descriptions are selected in such a way that some correlation exists between them. One description can be used for watermark insertion and the other description can be used as a reference for watermark extraction. After watermark insertion, two descriptions are combined to get the watermarked image. In this paper, two descriptions are considered based on odd and even pixel intensities of host image. Host image LENA as shown in Fig.1 (a) is decomposed into two descriptions odd and even as shown in Fig. 1(b) and Fig. 1(c).

Fig. 1(a) Host image LENA

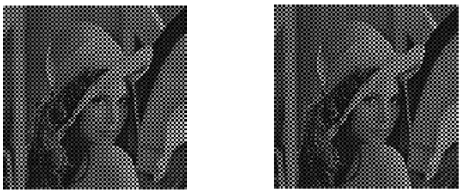


Fig. 1(b)LENA (odd description) (c) LENA (even description).

3. Discrete Contourlet Transform

DWT offers multistage and time-frequency localization of the image. However, it fails to represent the image effectively, if the image contains smooth contours in different directions. CT addresses this problem due to its inherent characteristics, viz., directionality and anisotropy.

CT uses double filter bank structures for obtaining sparse expansion of typical images having smooth contours. In this double filter bank structure, Laplacian Pyramid (LP) is used to capture the point discontinuities, and Directional Filter Bank (DFB) is used to link these point discontinuities into linear structures. As shown in Fig. 2, first stage is LP decomposition and second stage is DFB decomposition. LP decomposition is shown in Fig. 3. In LP decomposition of an image, let $f(i, j)$ (0<*i*,*j*<N) represent the original image and its down sampled low pass filtered version by $f_{lo}(i, j)$. The prediction error is given by

$$L_o(i, j) = f(i, j) - f_{lo}'(i, j) \quad (1)$$

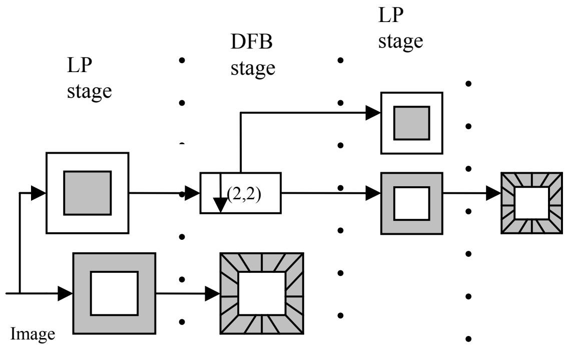


Fig. 2 Contourlet Filter bank

Here, $f_{lo}'(i, j)$ represents the prediction of $f(i, j)$. Encoding step is performed on $L_o(i, j)$ as it is largely decorrelated and requires less number of bits than $f(i, j)$. In Eq. (1), $L_o(i, j)$ represents a band pass image. Further encoding can be carried by applying Eq. (1) on $f_{lo}(i, j)$ iteratively to get $f_{l1}(i, j)$, $f_{l2}(i, j)$,. . . . . . . $f_{ln}(i, j)$, where *n* represents the pyramidal level number. In Fig. 3, H and G represent analysis and synthesis filters respectively. M represents sampling matrix. One level LP reconstruction is shown in Fig 5. The band pass image obtained in LP decomposition is further processed by a DFB. A DFB is designed to capture the high frequency content like smooth contours and directional edges. This DFB is implemented by using a *k*-level binary tree decomposition that leads to 2^k sub bands with wedge shaped frequency partition as shown in Fig 4.

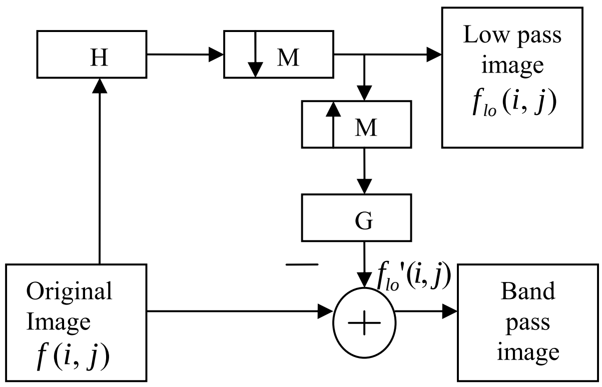


Fig. 3 One level LP decomposition.

In contourlet transform, DFB is implemented using quincunx filter bank with fan filters [10].

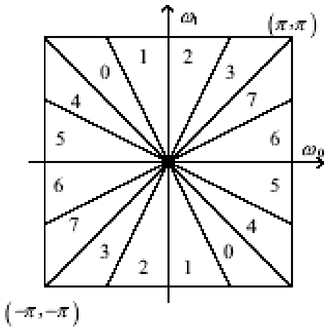


Fig. 4 Frequency partitioning (k=3, 2^k=8 wedge shaped frequency sub bands).

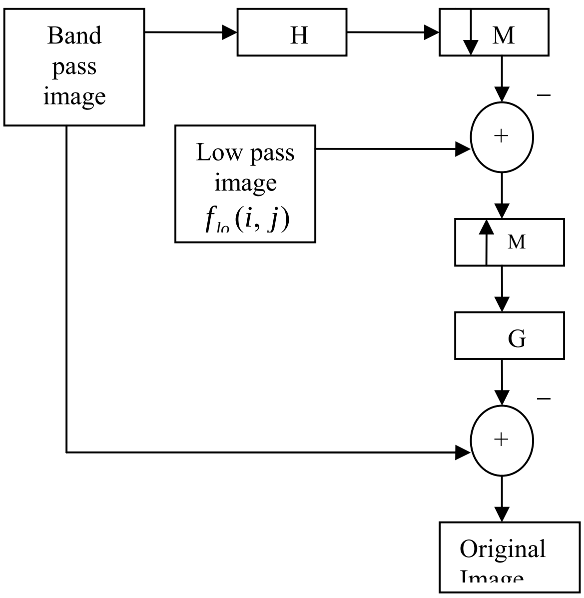


Fig. 5 One level LP reconstruction.

Contourlet decomposition is illustrated by considering LENA image of size 512x512 and decomposed into four levels as shown in Fig. 6. Top most band shown in Fig 6, is a low pass image. For LP decomposition, *n=(1,2,3,4).* At each successive level, number of directional sub bands is 2, 4, 8, and 16. Last directional sub band is selected for watermark embedding as this sub band possesses maximum energy compared to all other sub bands of same level as can be seen from Fig 7. Energy E of a sub band $s(i, j)$, $0 \le i, j \le N$ is computed by

$$E = \sum_i \sum_j |s(i, j)|^2 \tag{2}$$

Majority of the coefficients in the last sub band are significant (large) values compared to other sub bands of same level, indicating the presence of directional edges. Watermark embedded in directional edges improves the perceptibility of the watermarked image. The last directional sub band is shown in Fig.8 with proper thresholding, since it is the band where the first stage watermark is embedded.

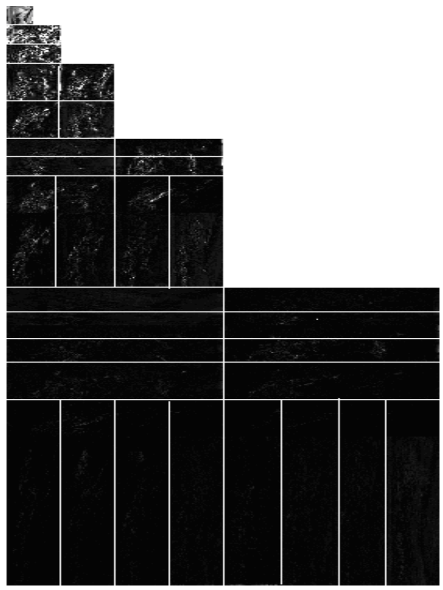


Fig. 6 Contourlet Decomposition of LENA

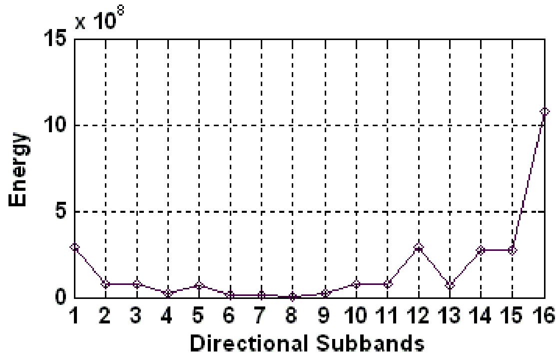


Fig. 7 Energy variation in the last level

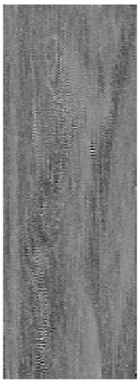


Fig. 8 Last directional sub band

4. Quantization Index Modulation

For the quantization of low pass image coefficients, dither quantization is used. Dither quantization is a variant of QIM [11]. Dither quantizers are quantizer ensembles. Each quantization cell in the ensemble is constructed from a basic quantizer. The basic quantizer is shifted to get the reconstruction point. The shift depends on the watermark bit. The basic quantizer is a uniform scalar quantizer with a fixed step size. The quantized value is the center of the quantizer. Maximum and minimum values of coefficients are identified and a quantization table is generated. The range of coefficients is divided into N equal sets. N is a positive constant that can be chosen to control the trade-off between robustness and transparency. For example, if the range of coefficients is [0 300] and the quantization step size being 60, a quantization table is generated as shown in Table 1.

Low pass image coefficients are modified as per the watermark bits. If the coefficient value is 70 and the watermark bit to be embedded is ‘1’ then the coefficient has to be modified as 75. This corresponds to the entry number 2. In this way, all the coefficients are modified according to the binary watermark bits. While extracting the watermarks from the watermarked image the coefficients are compared with the entries of the quantization table generated at the receiver as shown in Table 2.

Table 1 Quantization of coefficients

S.No	Range of coefficients		Modified coefficient value if watermark bit is	
			‘1’	‘0’
1	0	60	15	45
2	61	120	75	105
3	121	180	135	165
4	181	240	195	225
5	241	300	255	285

The quantization table can be generated at the receiver by knowing quantization step size and the range of coefficients. Usually, this range varies from image to image. An initial step size is assumed and it can be varied till an error free watermark is extracted.

Table 2 Quantization table generated at the receiver

S.No	Range of coefficients	
	Watermark bit ‘1’	Watermark bit ‘0’
1	0-30	30-60
2	60-90	90-120
3	120-150	150-180
4	180-210	210-240
5	240-270	270-300

5. Proposed Scheme

5.1. Watermark Embedding Technique

A binary watermark of size $\left(N/K \; x \; N/K\right)$, (where $K = 2^n$ and n represents the number of pyramidal levels used in CT decomposition) is embedded twice in the grey level host image of size NxN at two stages. In the first stage, host image is decomposed into two descriptions. CT is applied on both the descriptions. CT coefficients of the last directional sub band of odd description are modified as per watermark bits. This permits us to use second description as a reference, while extracting watermark at the receiver. In the second stage, CT is applied to the watermarked image obtained in the first stage. Application of CT results in a low pass image of size $\left(N/K \; x \; N/K\right)$ and other directional sub bands. By using QIM, coefficients of low pass image coefficients are modified according to the watermark bits. Various steps involved in watermark embedding are shown in Fig. 9.

Steps of embedding algorithm are as follows

1. The host image $f(i, j)$ of size *NxN* is partitioned into two descriptions. CT is applied to both the descriptions. A '*n*' $(l_1, l_2 \ldots\ldots l_n)$ level pyramidal structure is selected for LP decomposition. At each level l_k, there are 2^{l_k} directional sub bands, where *k*=1,2,3… *n*. Last directional sub band is selected for watermark embedding.

2. First $\left(N/_K \; x \; N/_K\right)$ coefficients of the last directional sub band of odd description are modified as follows:

$$D_{odd}^{lk}(i, j) = \alpha_1 * \; D_{even}^{lk}(i, j) \quad \text{if } w(i, j) = 1$$
$$D_{odd}^{lk}(i, j) = \alpha_2 * \; D_{even}^{lk}(i, j) \quad \text{if } w(i, j) = 0 \quad (3)$$

In Eq.(3), $D_{odd}^{lk}(i, j)$ represents l^{th} level, k^{th} directional sub band coefficient and *i*=1 to (N/K), j=1 to (N/K). In Eq.(3), $\alpha_1(>1)$ & α_2 (<1) are strength factors which can be used to control robustness and perceptual quality. Inverse Contourlet Transform (ICT) is applied by considering the modified directional sub bands to obtain watermarked image.

3. CT is applied to the watermarked image obtained in Step 2 and the low pass image coefficients of size $\left(N/_K \; x \; N/_K\right)$ obtained from CT decomposition are modified. This modification is based on scalar quantization as specified in QIM (Table 1).

4. Inverse Contourlet Transform (ICT) is applied to the modified sub bands and the final watermarked image is obtained.

5.2. Watermark Extraction Process

Parameter required for watermark extraction is only step size used in the quantization process. This is required for the generation of quantization table at the receiver. Watermark extraction process is summarized in Fig. 10.
Steps of watermark extraction algorithm are as follows

1 . Partition the watermarked image of size *NxN* into odd and even descriptions. CT is applied to both the descriptions.

2 . Last directional sub band coefficients of odd description are compared with the last directional sub band coefficients of even description. Watermark at stage 1 is generated as follows.

$$w(i, j) = 1 \quad \text{if } D_{odd}^{lk}(i, j) > D_{even}^{lk}(i, j)$$
$$w(i, j) = 0 \quad \text{if } D_{odd}^{lk}(i, j) < D_{even}^{lk}(i, j) \quad (4)$$

3. CT is applied to watermarked image and a low pass image is obtained by using 'n' level LP and DFB decomposition.

4. A quantization table is generated at the receiver (Table 2). The position of low pass image coefficients is identified and accordingly watermark bits are generated from the quantization Table. 2

Benefits of embedding the watermark at two stages in two different ways are two fold: If faithful watermark extraction is not achieved at the first stage, there exists a fair amount of probability that it survives at the second stage. In first stage, CT directional sub band coefficients are compared for watermark embedding. Many global attacks like histogram equalization, sharpening, gamma correction and blurring change the pixel intensity values. Change in CT coefficients is same for both the descriptions and hence error free extraction is possible. To resist local attacks like JPEG compression and resizing operation, quantization of low pass image coefficients is used. In this way, watermark can survive to both local and global attacks. Contourlet transform is selected for watermark embedding because, it captures directional edges and smooth contours well. Human visual system is less sensitive to edges. Hence, the perceptibility of watermarked image can be improved by embedding the watermark image in edges. When a watermark is embedded in the low pass image of CT decomposition, the perceptibility of the watermarked image is degraded, but it is highly robust. Visual quality of the image can be improved by embedding the watermark in the sub bands. But, it is hardly robust. To achieve both robustness and good visual quality, same watermark is embedded in both low pass image and directional sub band.

The error metrics used to test the proposed algorithm are Normalized Cross correlation (NC) and peak signal to noise ratio (PSNR). Let the host image of size *NxN* is $f(i, j)$ and the watermarked counterpart is $F(i, j)$.

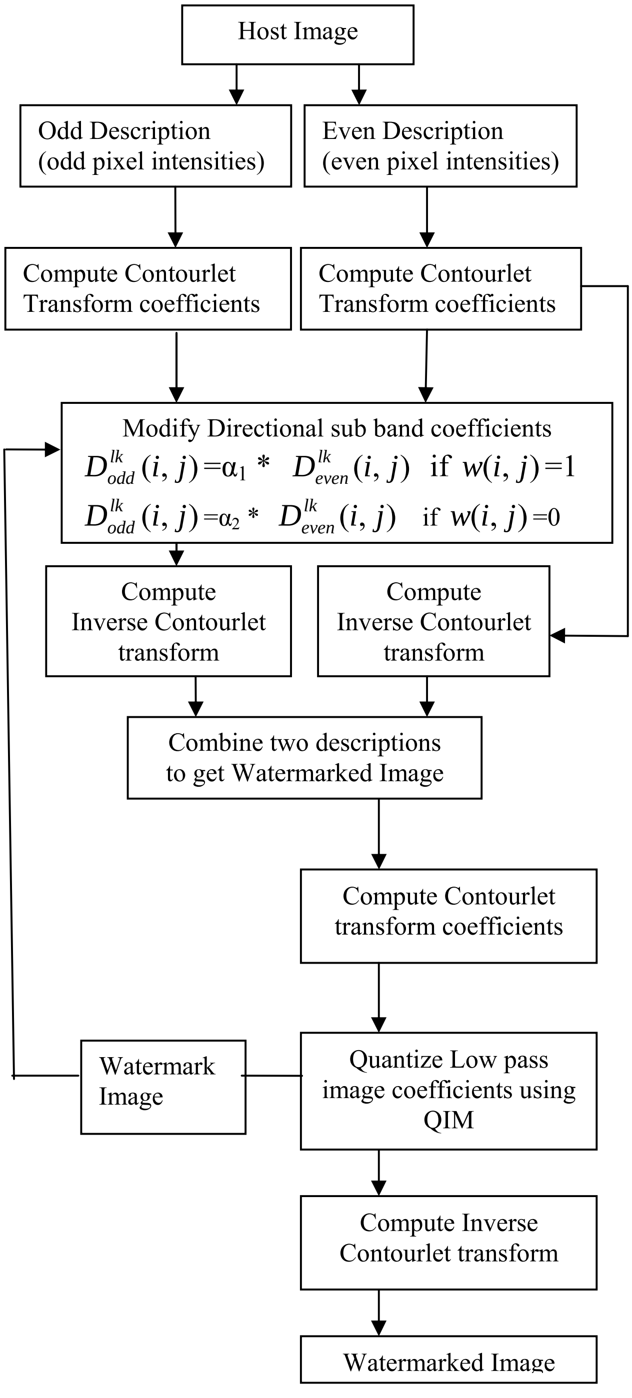


Fig. 9 Embedding Algorithm

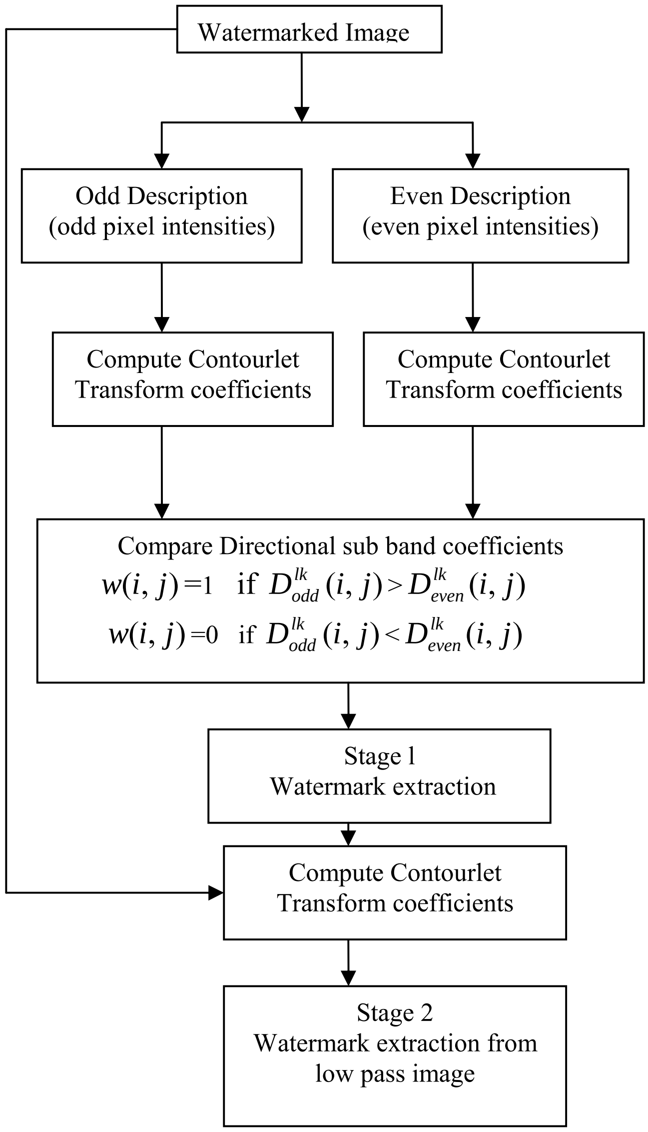


Fig. 10 Extraction Algorithm

PSNR in dB is given by

$$\mathrm{PSNR} = 10\log_{10}\left(\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(F(i,j))^2}{\sum_{i=1}^{N}\sum_{j=1}^{N}(f(i,j)-F(i,j))^2}\right) \tag{5}$$

Let the watermark image is denoted by $w(i,j)$ and the extracted watermark is denoted by $w'(i,j)$ then NC is defined as

$$\text{NC}=\left(\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i,j)-w_{mean})(w'(i,j)-w'_{mean})}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i,j)-w_{mean})^2\sum_{i=1}^{N}\sum_{j=1}^{N}(w'(i,j)-w'_{mean})^2}}\right) \quad (6)$$

In Eq.(6), w_{mean} and w'_{mean} indicate the mean of the original watermark image and extracted watermark image respectively.

6. Experimental Results

Lena image of size 512x512 is considered as host image. The watermark image is of size 32x32, which is a binary logo having the letters '**JNTU**' . Watermarked LENA and binary logo are shown in Fig. 12 and Fig. 13 respectively. Tampered LENA is shown in Fig. 14. The parameters used in the work are á$_1$=1.2, á$_2$=0.9. In both LP decomposition and DFB decomposition, 'pkva' filters [12] are used because of their efficient implementation. Number of pyramidal levels are four (1,2,3,4). At each successive level, number of directional sub bands are 2, 4,8, and 16 respectively. Step size used in the quantization process is 30. MATLAB 7.0 and Checkmark 1.2 [13]are used for testing the robustness of the proposed scheme. JPEG2000 attack is tested using MORGAN JPEG2000 tool box [14]. Various attacks used to test the robustness of the proposed watermark are resizing, JPEG, JPEG2000, soft thresholding, median filtering, template removal, trimmed mean alpha, wiener filtering, gray scale inversion, salt &pepper noise, gaussian low pass filtering, cropping, row column copying, gamma correction, bit plane removal, image sharpening, histogram equalization, frequency mode laplacian removal and image tampering. Extracted watermarks, after applying various attacks are summarized in Table 3.Third column and fourth column in the Table.3 shows the watermark extracted from stage 1 and stage 2 respectively. NC values are also indicated. Performance of the proposed method is compared with Wang et al.'s method and shown in Table 4.

Table 3: Extracted Watermarks

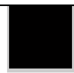
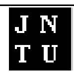
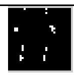
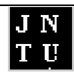
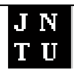
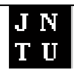
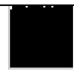
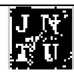
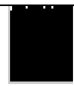
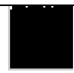
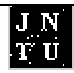
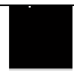
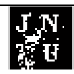
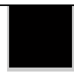
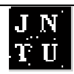
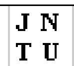
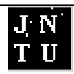
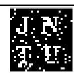
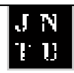
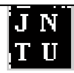
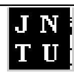
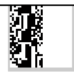
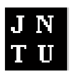
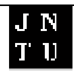
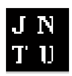
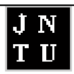
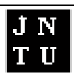
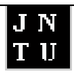
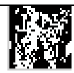
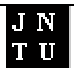
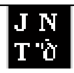
Attack	Attack Parameters	Stage 1	Stage 2
Resizing	50%	 0	 1
JPEG Compression	QF=80	 0.3698	 0.9954
JPEG 2000 Compression	QF=50	 1	 0.9989
Soft Thresholding	3x3 window	 0.02	 0.6181
Median Filtering	3x3 window	 0.0211	 0.5063
Template Removal	3x3 Window	 0.0322	 0.9255
Trimmed Mean Alpha	3x3 Window	 0.0087	 0.6619
Wiener Filtering	3x3 Window	 0	 0.9295
Grey Scale Inversion	-	 -0.3	 -1
Salt & Pepper Noise	0.001 Noise density	 0.9732	 0.7069
Gaussian LPF	3x3 kernel	 0.9020	 0.9060
Cropping	50% right half	 0.9002	 0.208
Row & Column copying	10-30,40-70,100-120 Copied	 1	 0.273
Gamma Correction	0.5	 0.96	 0.1096
Bit plane Removal	LSB	 1	 0.2590

Image Sharpening	3x3 window	 0.9819	 0.24
Histogram Equalization	-	 0.9954	 0.024
Frequency mode Laplacian removal	-	 0.9861	 0.15
Tampered Lena	Nose is tampered	 1	 0.8858

Wang et al.'s method is also a blind watermarking technique based on patch work estimation. A total of 910 watermark bit are embedded in LENA by using DCT. PSNR reported is 39.21 dB and the number of attacks reported are only 4. In the proposed method, 1024 bits are embedded and PSNR obtained is 39.37 dB. Watermark image can survive to many attacks compared to Wang et al.'s method.

Fig. 12 Watermarked LENA (PSNR=39.37 dB)

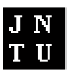


Fig. 13 Watermark Image

Fig. 14 Tampered LENA

Table 4: Comparison of Proposed Method with Wang et al., method.

Characteristic	Proposed Method	Wang et al., Method
No of Watermark Bits embedded	1024 (32x32 logo)	910
PSNR in dB	39.37	39.21
No of attacks reported	20	4
Type of embedding	Oblivious	Oblivious

7. Conclusions

In this paper, a novel and oblivious watermarking scheme based on multiple description of host image and scalar quantization of low pass image of Contourlet decomposition is presented. Embedding of watermark is done at two stages. At the first stage, watermark is embedded in the directional sub band of contourlet decomposition of odd description. In the second stage, watermark is embedded in the low pass image coefficients of the contour let decomposition. Proposed method is highly robust and can survive many attacks. The quality of the watermarked image is good in terms of perceptibility and PSNR (39.37dB). Proposed algorithm is shown to be robust to resizing, JPEG, JPEG2000, soft thresholding, median filtering, template removal, trimmed mean alpha, wiener filtering, gray scale inversion, salt &pepper noise, Gaussian low pass filtering, cropping, row column copying, gamma correction, bit plane removal, image sharpening, histogram equalization, frequency mode laplacian removal and image tampering. Compared to Wang et al. method, the proposed method is superior in terms of embedding capacity, PSNR and survival to number of image attacks.

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