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Contourlet versus Wavelet Transform for a Robust Digital Image Watermarking Technique

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***Abstract*—**In this paper, a watermarking algorithm that uses the wavelet transform with Multiple Description Coding (MDC) and Quantization Index Modulation (QIM) concepts is introduced. Also, the paper investigates the role of Contourlet Transform (CT) versus Wavelet Transform (WT) in providing robust image watermarking. Two measures are utilized in the comparison between the wavelet-based and the contourlet-based methods; Peak Signal to Noise Ratio (PSNR) and Normalized Cross-Correlation (NCC). Experimental results reveal that the introduced algorithm is robust against different attacks and has good results compared to the contourlet-based algorithm.

***Keywords*—**image watermarking; discrete wavelet transform; discrete contourlet transform; multiple description coding; quantization index modulation.

I. Introduction

NOWADAYS, copyright protection of digital information became essential due to the vast growth of the digital media access and editing over networks. Usually, the ownership is digitally protected by embedding copyright information, called watermark, on digital data.

In general, a digital watermarking technique should be transparent (or perceptually invisible for image data) and resistant to attacks that may remove it or replace it with another watermark. This means that the watermark should be robust to common signal processing operations, such as, filtering, compression, rotation, and others. Recent image watermarking algorithms utilize image transforms such as Discrete Cosine Transform (DCT) [1], Discrete Wavelet Transform (DWT) [2 and 3], and Discrete Contourlet Transform (CT) [4, 5, and 6]. Transform domain watermarking schemes tend to amend the transform coefficients based on the bits of watermark image. Latest watermarking algorithms are based on the Discrete Contourlet Transform (CT) which is capable of capturing the directional edges of the image at different scales [7] better than the popular DWT. However, the later is still having some properties and superiority over the CT. In this paper, a DWT-based watermarking technique is introduced and compared to the CT-based algorithm given in [4]. The rest of the paper is organized as follows: In Section 2, DWT versus CT is discussed. MDC is presented in Section 3. QIM is discussed in section 4. An image watermark embedding and extraction algorithm is given in section 5. Experimental results are presented in section 6. Section 7 draws Conclusions.

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II. DWT versus CT

A. Discrete Wavelet Transform (DWT)

The DWT is a powerful and a popular transform familiar to image processing community. In two dimensional applications, the DWT decomposes a given image into four subbands (i.e. LL1, HL1, LH1, and HH1). The subband (LL1) represents the low frequency part where most energy is concentrated, while the other subbands represent the high frequency content in the horizontal, vertical and diagonal directions. To obtain the next wavelet level, the subband (LL1) is further decomposed into another four subbands. This process can be repeated several times until the required decomposition level is reached. Figure 1 shows an example of three level wavelet decomposition subbands.

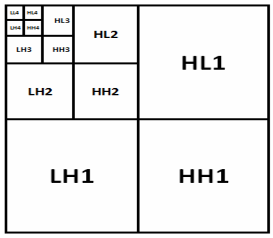

Fig.1 Three level DWT decomposition

B. Contourlet Transform (CT)

The Contourlet Transform (CT) is a new image decomposition scheme introduced by Do and Vetterli [7]. CT is more effective in representing smooth contours in different directions of an image than the Discrete Wavelet Transform. The CT can be divided into two main steps: Laplacian Pyramid (LP) decomposition and Directional Filter Banks (DFB) decomposition. An image is first decomposed into low pass image and band pass image by LP decomposition. Each bandpass image is further decomposed by DFB step. A DFB is designed to capture the high frequency content like smooth contours and directional edges. Multi-resolution and multi-direction decomposition can be obtained by repeating the same steps mentioned above for the low pass image.

In Contourlet, the number of directional subbands at each level is set to 2^n where n is a positive integer number. For example, if we choose to decompose an image into four levels using n= (1, 2, 3, 4) then we get 2, 4, 8, and 16 subbands as shown in Figure 2.

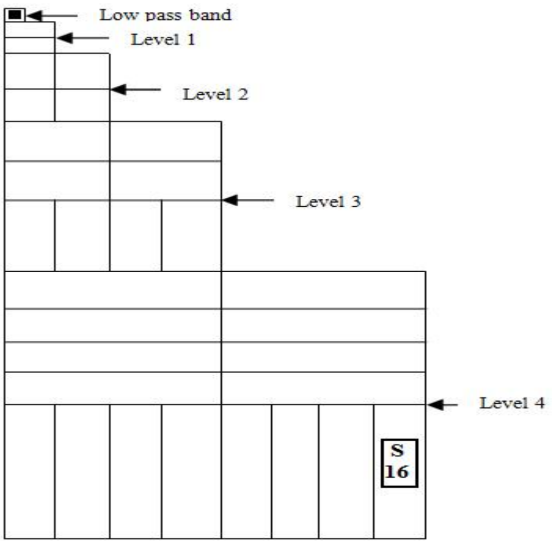

Fig. 2 Contourlet decomposition

In [4] the last directional sub band was selected for watermark embedding as this subband has the highest energy compared to all other sub bands of the same level. This selection is also confirmed in this paper as shown in Figure 3. However, in wavelet decomposition the diagonal sub band has the maximum energy compared to the other sub bands as illustrated in Figure 4. This energy is higher than the energy of the sub band number 16 in contourlet so that the diagonal sub band in wavelet is chosen, in this paper, for the embedding process.

The last directional sub band in contourlet and the diagonal sub band in wavelet are the sub bands where the first stage watermark is embedded and then compared. Furthermore, these sub bands are compared to the other sub bands in the same level; which improves the perceptibility of the watermarked image because the large values indicate the presence of directional edges.

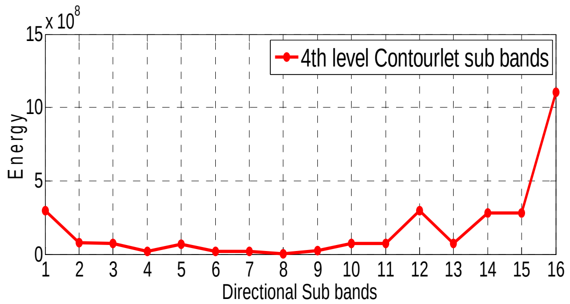

Fig. 3 Fourth level contourlet energy variation (similar to [4])

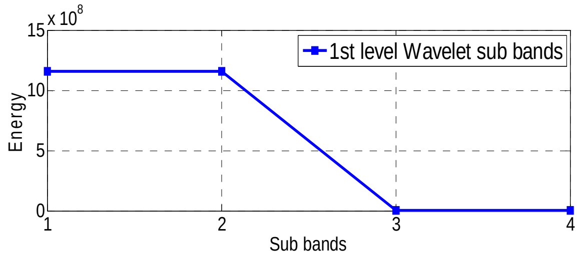

Fig. 4 First level wavelet energy variation (1=LL, 2=HH, 3=LH, 4=HL)

III. Multiple Description Coding

The Multiple Description Coding (MDC) partitions an image into various descriptions such that the image can be reconstructed from one or more of these source descriptions within some prescribed distortion constraints. The concept of MDC can be used in digital image watermarking as suggested by Chandramouli et al. [8]. Consequently, one description of an image with two descriptions can be used as a reference and the other one for watermark insertion. In this paper, the host image is divided into two descriptions, the first one is used for the watermark embedding and the second one is used as a reference in the extraction process. The watermarked image results from the combination of the two descriptions the watermark is embedded.

IV. Quantization Index Modulation

Quantization is an approximation step which is considered as a lossy data compression method. Low pass image coefficients are quantized using Dither quantizer which is a variant of QIM [9]. Based on the watermark bit a uniform basic quantizer is shifted to get the reconstruction point. The quantization step is computed from the dynamic range of coefficients which is divided into M equal sets that control the transparency of the image and robustness of the watermark. The modification of low pass image coefficients is done based on the watermark bits. Having the range of coefficients and the quantization step size values helps us to generate the quantization table at the receiver. The coefficients of the watermarked image are compared with the values of the quantization table generated at the receiver to extract the watermark from the watermarked image.

V. Waternarking Algorithm

A. *Watermark Embedding Process*

In this paper, the contourlet-based algorithm proposed by Chandra [4] is modified. The quantization of the low pass image is changed as the step size is reduced which enhances the robustness and the perceptibility of the watermarked image. Furthermore, the Contourlet transform is replaced with the wavelet transform then the performances of the two transforms are compared. It is investigated whether the contourlet with their extra features would provide any significant advantages over the wavelets in terms of watermark robustness and invisibility. The embedding algorithm steps (which are similar to [4] with modifications to the step size, the transformation, and the number of subbands) are as follows:

- The host image *f(i,j)* of size NxN is divided into two descriptions. The two descriptions are transformed by first level DWT. At the first level there are four sub bands i.e. (LL1, LH1, HL1, and HH1) for each description. The diagonal sub band (HH1) is chosen for the first stage watermark embedding process.
- Select the first (32x32) coefficients of the first description of the diagonal sub band for modification based on watermark bits as follows:

$$C_1(i,j) = b * C_2(i,j), \tag{1}$$

where $C_1(i,j)$ and $C_2(i,j)$ are the coefficient values at the same level of the first and second descriptions respectively, i=1 to 32, and j=1 to 32. The parameter b is the strength factor which can be used to control the robustness and the perceptual quality. This strength factor can take values (b>1 for $w(i,j)=1$) & (b<1 for $w(i,j)=0$). Inverse DWT is applied to both descriptions by considering the modified sub band. To get the watermarked image the two descriptions are combined.

- Second stage watermark embedding is done by transforming the Watermarked image obtained in the previous step by applying DWT for four levels to get the low pass image coefficients of size (32x32). Coefficients of low pass image are quantized by scalar quantizer as in QIM based on watermark bit.
- Modified sub bands which contain the quantized coefficients values are transformed by Inverse DWT to get the final watermarked image.

B. Watermark Extraction Process

Step size used in the quantization process is needed in the extraction process to generate the quantization table at the receiver. Watermark extraction algorithm steps are as follows:

- Watermarked image is divided into the two descriptions. Both descriptions are transformed by first level DWT.
- Coefficients of the first description of the diagonal sub band are compared with coefficients of the second description of the diagonal sub band. First stage watermark extraction is done as follows:

$$\begin{aligned} w(i,j) &= 1 \quad \text{if} \quad C_1(i,j) > C_2(i,j) \\ w(i,j) &= 0 \quad \text{if} \quad C_1(i,j) < C_2(i,j) \end{aligned} \tag{2}$$

- Low pass image coefficients of the watermarked image are computed by applying DWT for four levels.
- Watermark bits at stage 2 are extracted from the quantization table (generated at the receiver) according to the low pass image coefficients values.

Embedding the watermark at two stages has an important benefit [4]; if the first watermark extraction failed then the second watermark will survive as they are embedded in two different ways. The first stage watermark is robust to global attacks like histogram equalization and sharpening, whereas the second stage is made robust to local attacks (like JPEG compression) by the quantization of the low pass image coefficients. Therefore, the algorithm is robust to both global and local attacks. Embedding the watermark in the high frequency sub bands of CT and WT which contains edges improves the perceptibility of the watermarked image since the human visual system is less sensitive to edges [4].

Two quality measures are used to investigate the robustness of the proposed algorithm. The first measure is the Peak Signal to Noise Ratio (PSNR) which is used to evaluate the quality of the watermarked image. Let the host image of size NxN is f(i,j) and the watermarked counterpart is f'(i, j).

$$PSNR = 20\log_{10}\left(\frac{MAX_f}{\sqrt{MSE}}\right) \tag{3}$$

Where MAX_f is the maximum possible pixel value of the image, and MSE is the mean squared error

$$MSE = \frac{1}{N^2}\sum_{i=0}^{N-1}\sum_{j=0}^{N-1}\left\| f(i,j) - f'(i,j)\right\|^2 \tag{4}$$

The second measure is the Normalized Cross-Correlation (NCC) which is used to prove the authenticity of the extracted watermark. If the watermark image is denoted by *w*(i,j) and the extracted watermark is denoted by *w'*(i, j) then NCC is calculated as

$$NCC = \left(\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i,j)-w_m)(w'(i,j)-w'_m)}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i,j)-w_m)^2(w'(i,j)-w'_m)^2}}\right) \tag{5}$$

where w_m and w'_m indicating the mean of the original watermark image and extracted watermark image, respectively.

VI. Experimental Results

In order to easily compare with other watermarking techniques in the literature, a standard 512x512 gray-level Lena image is used as the host image. The watermark image is made from a binary loge image having the letters ‘AAST’ of size 32x32 pixels. The strength factor used in the algorithm is set to b=1.2 for $w(i,j)=1$ and b=0.9 $w(i,j)=0$ (same as in [4]). In contourlet decomposition, both LP decomposition and DFB decomposition with ‘pkva’ filters [10] are used. The first four pyramidal levels are chosen and the number of directional sub bands for each level is set to 2, 4, 8, and 16 respectively. In wavelet decomposition, ‘haar’ filters are used because of their high efficiency. The decomposition tree is done for four levels (same as in contourlet-based algorithm). The step size used in the quantization of low pass image is reduced to three which is much smaller than the value used in [4].

MATLAB 7.4 and Checkmark 1.2 [13] are used for implementing and testing the robustness of the proposed algorithm against different attacks. JPEG2000 attack is tested using Able Batch Converter 3.1 [12]. JPEG attack is tested using MORGAN JPEG tool box [13]. Figures 5 and 6 show the watermarked LENA in both CT and WT based algorithms and binary logos, respectively

Testing the robustness is done by applying a number of different attacks which are JPEG, JPEG2000, hard thresholding, median filtering, template removal, wiener filtering, salt & pepper noise, Gaussian low pass filtering, cropping, image sharpening, and histogram equalization. Table I shows the extracted watermark image from stage 1 and stage 2 in contourlet-based (CT) algorithm & stage 1 and stage 2 in wavelet-based (WT) algorithm. The performance of the watermark extraction in measured by the NCC value which is shown below each extracted watermark image.

Three attacks applied to the watermarked images for the two algorithms are compared against the window size. Median filtering is one of the most popular nonlinear enhancement techniques. The corresponding PSNR values are plotted against the window size of the median filter in figure 7 which shows that the wavelet-based watermarking algorithm outperforms the contourlet-based algorithm for widow sizes below 5. Wiener filtering is another kind of enhancement techniques which is also applied to the watermarked images. Figure 8 shows the PSNR values against different window sizes of wiener filter. Furthermore, hard thresholding attack is tested against different window sizes as shown in Figure 9. The plots of figures 8 and 9 indicate that wavelet-based algorithm has slightly better PSNR performance than the contourlet-based algorithm.

TABLE I. EXTRACTED WATERMARKS

Attack	Attack param.	Stage 1 CT	Stage 2 CT	Stage 1 WT	Stage 2 WT
JPEG compression	QF=80	0.8479	0.9906	0.8825	0.9953
JPEG2000 Compression	QF=50	1	0.9952	1	1
Median Filtering	3x3 window	-0.0113	0.8861	0.3022	0.7657
Hard Thresholding	3x3 window	0.5573	0.5786	0.1077	0.5966
Template Removal	3x3 window	0.3247	0.9545	0.9509	0.8171
Wiener Filtering	3x3 window	0.3247	0.9545	0.9551	0.8846
Salt & pepper noise	0.001 noise density	0.9769	0.9023	0.9953	0.8667
Gaussian LPF	3x3 window	1	0.9386	1	0.9582
Cropping	Upper left corner	0.9769	0.003	1	-0.0422
Image Sharpening	3x3 window	0.9386	0.7411	1	-0.003
Histogram Equalization	-	0.9725	-0.0556	1	0.0079

CT (PSNR= 40.339) WT (PSNR= 40.61dB)

Fig. 5. Watermarked LENA

Fig. 6. Watermark image

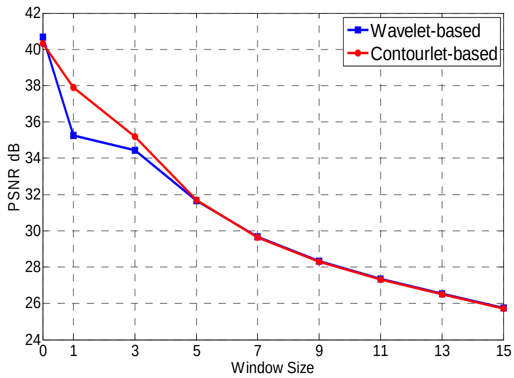

Fig. 7. PSNR against window size of median filter

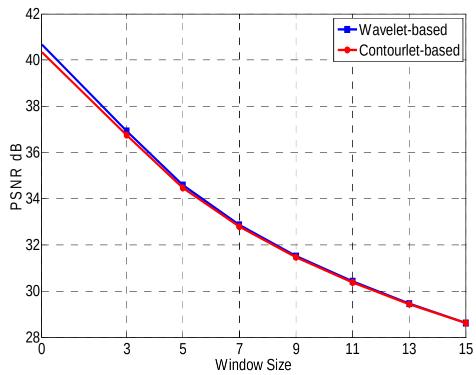

Fig. 8 PSNR against window size of wiener filter

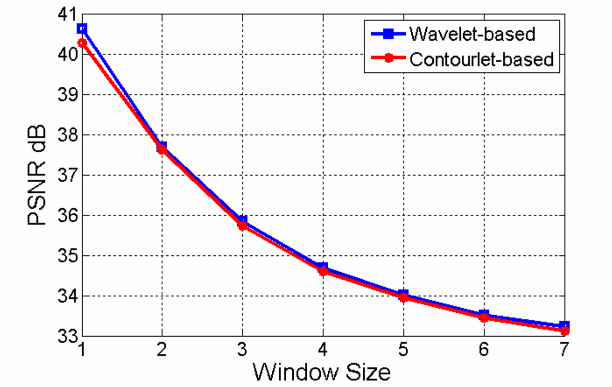

Fig. 10 PSNR against window size for hardthresholding attack

VII. Conclusions

This paper proposes a wavelet-based watermarking technique and compares it to a contourlet-based watermarking algorithm. Both algorithms use multiple descriptions coding of host image and scalar quantization of low pass image. Furthermore, the step size used in the quantization process is reduced which improves the perceptibility of the watermarked image. The results of the presented algorithm show highly robustness against different image attacks. The wavelet-based algorithm demonstrates better performance than the contourlet-based algorithm in most attacks. In comparison with Chandra's method [4], the PSNR of the proposed WT-based algorithm (40.61dB) is better than both the modified CT-based algorithm (40.339dB) and Chandra's CT-based algorithm (39.37dB).

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