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A Robust Hybrid Blind Digital Image Watermarking System Using Discrete Wavelet Transform and Contourlet Transform

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Abstract**—**In this paper, a hybrid blind digital watermarking system using Discrete Wavelet Transform (DWT) and Contourlet Transform (CT) has been implemented and tested. The implemented combined digital watermarking system has been tested against five common types of image attacks. The performance evaluation shows improved results in terms of imperceptibility, robustness, and high tolerance against these attacks; accordingly, the system is very effective and applicable.

Keywords**—**DWT, contourlet transform, digital image watermarking, copyright protection, geometric attack.

I. Introduction

NOWADAYS the advent of the Internet has resulted in many new opportunities for the creation and delivery of content in digital form. These web-based applications content include documents, images, audio, and video. An important issue that arises is the protection of rights of all participants. One of the protection mechanisms that attract many researchers is based on digital watermarking techniques.

Digital watermarking is a process of information hiding which is used to hide secret information (which we call the watermark) in multimedia data like digital images, text documents, audios, or video clips. In specific, a digital image watermark is a label that is embedded inside an image. It acts as a digital signature, giving the image a sense of ownership or authenticity.

Digital watermarking algorithms or transforms can be classified into blind and non-blind algorithms according to weather the original image is required to extract the watermark. Non-blind algorithms need the original image to extract the watermark; whereas Blind algorithm does not need original image in extraction. In this paper, we restrict our attention on blind algorithms.

Commonly used transforms are DWT, Discrete Cosine Transform (DCT), and CT. DWT is the most popular transform in comparison with other transforms [3], [6]. But this technique does not possess directional information such as the directional edges of the image. CT has been developed as an improvement over wavelet [7], [8]. CT has the capability of capturing directional information with multiresolution representation such as smooth contours and directional edges [4], [10]. So that, CT is well suited for images like maps were a lot of curves and text are present [1]. Further performance improvements have been done by many researchers based on DWT by combining DWT with other transform algorithms such as DCT transform [2], [9], [13], CT Transform [1], [5], [12], or HWT wavelet transform [11].

In this paper, performance evaluation has been done on our previous blind digital image watermarking algorithm based on combining DWT and CT [1]. The experimental results showed that the combined two transforms improve the imperceptibility and the robustness in comparison with the DWT and the CT transforms separately.

II. Related Works

Shilbayeh et al. [1] proposed a blind digital image watermarking algorithm that is based on combining DWT, and CT. A searching process point is used to find the best sub-band for embedding which increase the robustness and the imperceptibility at the same time.

Amirgholipour and Naghsh-Nilchi [2] proposed a robust image watermarking algorithm based on joint DWT-DCT transform. A binary watermarked logo is embedded in coefficient sets of 3-levels DWT on a host image. Then, a 4×4 block-based DCT is performed on the selected DWT coefficient sets. In the extraction procedure, pre-filtering operation is used before applying DWT transform on a host image. Then, the same procedure is done as the embedding one.

Shilbayeh and Ashimary [11] represented a new robust HWT-DWT hybrid watermarked algorithm. The proposed method is constructed by cascading two different but complimentary techniques for image protection by using watermarking techniques.

Al-Haj et al. [13] proposed a robust combined DWT-DCT digital watermarking transforms algorithm. The combined transforms shows a positive impact on the performance in comparison with the DWT transform alone.

III. The Combined DWT-CT Digital Watermarking Algorithm

In our performance evaluation, we used the combined DWT-CT transform proposed by [1]. Fig. 1 shows the sequence of the combined DWT-CT techniques used in the

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algorithm development.

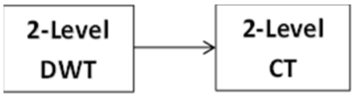

Fig. 1 DWT-CT Watermarking

The combined DWT-CT Algorithm consists of two parts; embedding algorithm and extraction algorithm.

A. Embedding Algorithm Based on DWT-CT

Fig. 2 shows the block diagram of the watermark embedding algorithm. More details about the embedding algorithm can be found in [1].

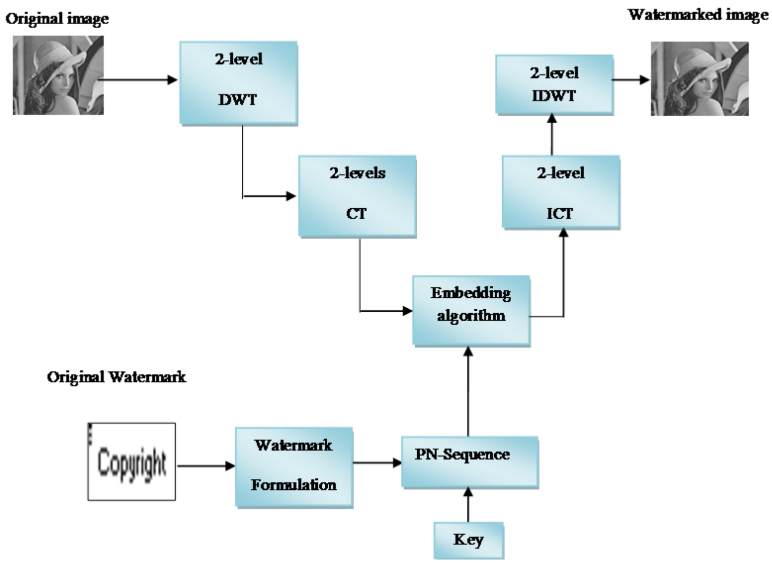

Fig. 2 DWT-CT Watermark embedding block diagram [1]

B. Extracting Algorithm Based on DWT-CT

Fig. 3 shows the block diagram of the watermark extraction algorithm. More details about the embedding algorithm can be found in [1].

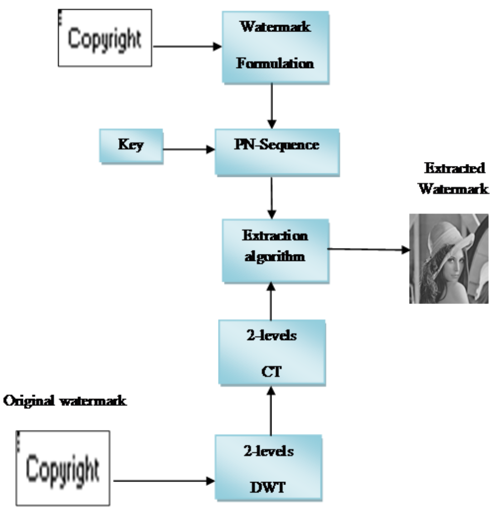

Fig. 3 DWT-CT Watermark extraction block diagram [1]

IV. Performance Evaluation

The performance evaluation of combined DWT-CT algorithm has been evaluated using Peak Signal to Noise Ratio (PSNR) which measures imperceptibility and the Normalized Cross Correlation (NCC) which measures robustness.

A. Imperceptibility

The PSNR and the Mean Square Error (MSE) are used to test the quality of the watermarked image. MSE is calculated using:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\left\| I(i,j) - K(i,j) \right\|^2$$

where, I is the original image, K is the watermarked image that contain (m) by (n) pixels as in [1]. PSNR is calculated using:

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX^2{}_I}{MSE}\right) = 20 \cdot \log_{10}\left(\frac{MAX_I}{\sqrt{MSE}}\right).$$

where, MAX_I is the maximum possible pixel value of the image as in [1].

The visibility of the implementation of the combined algorithm was tested by calculating the PSNR between the original image and the watermarked image. The result of the tested PSNR value is equal to 88.112.

B. Robustness

The robustness of the combined DWT-CT algorithm has been tested by adding 5 types of attacks to watermarked images (Gaussian noise, Rotation, Cropping, Compression using JPEG compression and dithering). The effects of these 5 attacks are measured by the NCC.

C. Effect of Gaussian Noise

Gaussian noise has been added to the watermarked image. We used a fixed value for the variance and changed the mean. Fig. 4 shows the attacked watermarked image at diferent values of the mean to the embeded watermarked image based on DWT-CT. The extracted watermark and the correlation values between the original and the extracted watermark at different values of the mean are shown in Figs. 5 and 6 respectively.

Fig. 4 The attacked watermarked image by noise based on DWT-CT

Fig. 5 The extracted watermark image after noise based on DWT- C

D. Effect of Rotation

The digital watermarked image has been rotated by using different angels from 0 to 300 anti-clockwise. Fig. 7 shows the attacked watermarked image at different values of angles to the embedded watermarked image based on DWT-CT. The extracted watermark and the correlation values between the original and the extracted watermark at different values of angles are shown in Figs. 11 and 12 respectively.

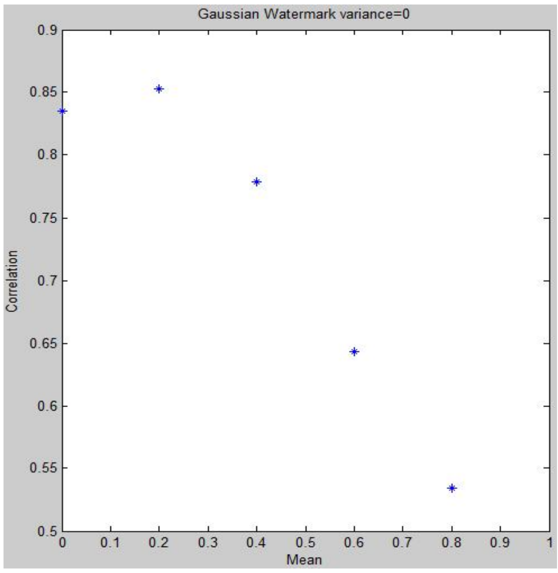

Fig. 6 Correlation due to noise attacks based on DWT-CT

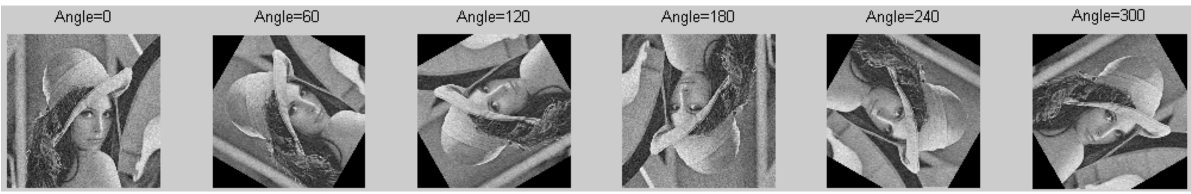

Fig. 7 The attacked watermarked image by rotation based on DWT- CT

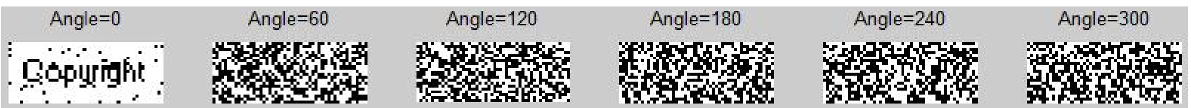

Fig. 8 The extracted watermark image after rotation based on DWT- CT

E. Effect of Cropping

The digital watermarked image has been cropped by different block sizes. Fig. 10 shows the attacked watermarked image at diferent values of the block size to the embeded watermarked image based on DWT-CT. Figs. 11 and 12 show the extracted watermark and the correlation values after cropping attacks based on combined DWT-CT transforms.

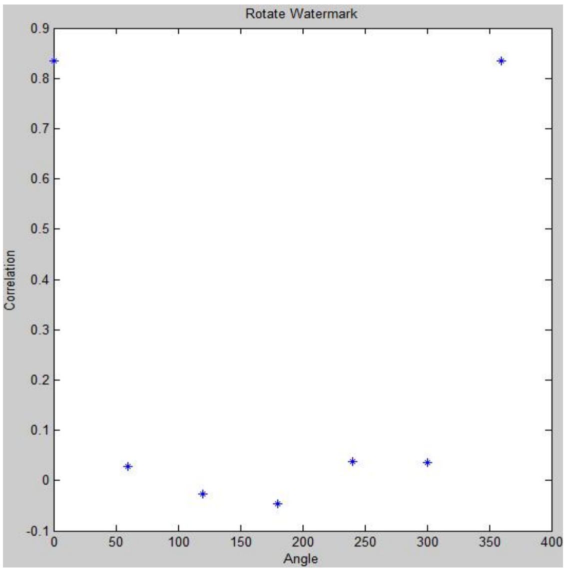

Fig. 9 Correlation due to rotation attacks based on DWT-CT

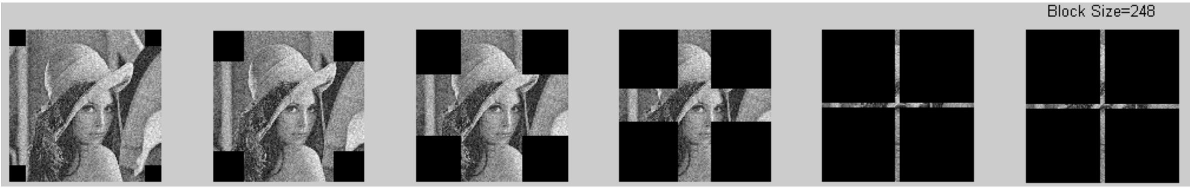

Fig. 10 The attacked watermarked image by cropping based on DWT- CT

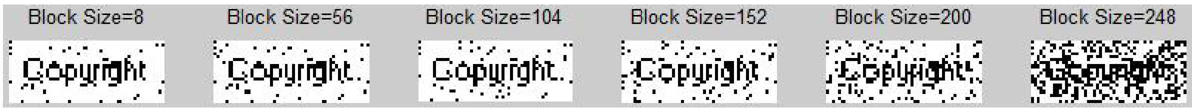

Fig. 11 The extracted watermark image after cropping based on DWT- CT

F. Effect of JPEG Compression

The digital watermarked image has been compressed using Lossy compression with different quality values. Fig. 13 shows the attacked watermarked image at different quality values to the embeded watermarked image based on DWT-CT. The extracted watermark and the correlation values between the original and the extracted watermark at different quality values are shown in Figs. 14 and 15 respectively.

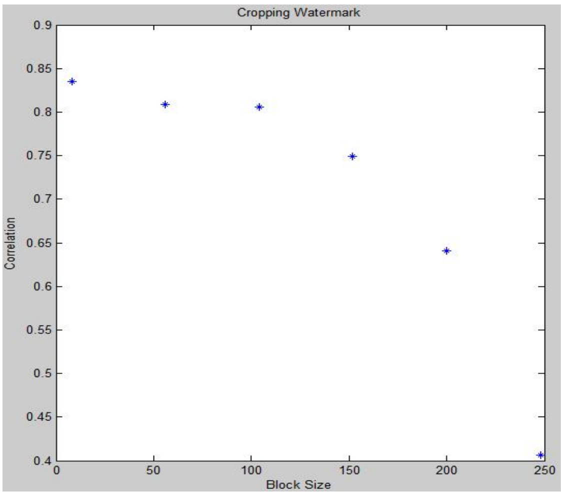

Fig. 12 Correlation due to cropping attacks based on DWT-CT

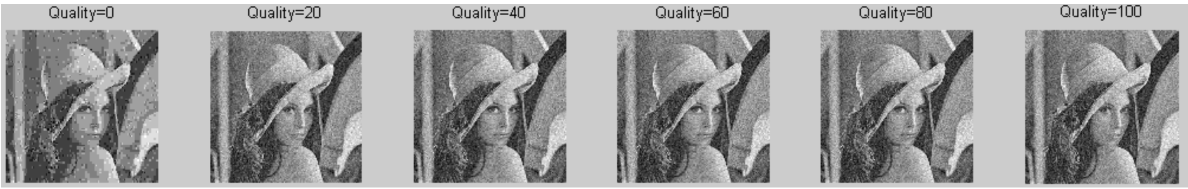

Fig. 13 The attacked watermarked image by JPEG compression based on DWT-CT

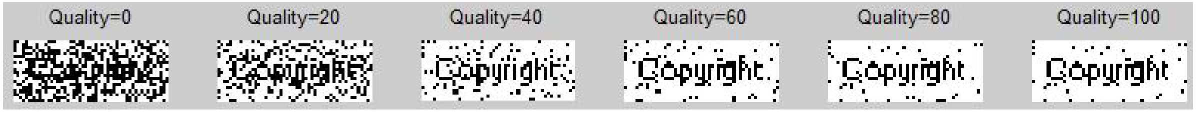

Fig. 14 The extracted watermark image after JPEG compression based on DWT- CT

G. Effect of Dithering

Dithering has been used with the watermarked image. We dithered the watermarked image by fixing the value of Q_m at 5 and changed the value of Q_e, where Q_m represents the number of quantization bits used along each color axis for the inverse color map, and Q_e represents the number of quantization bits used for color errors. Fig. 16 shows the attacked watermarked image at different values of Q_m to the embedded watermarked image based on DWT-CT. Figs. 17 and 18 show the extracted watermark and the correlation values after dithering attacks based on the combined DWT-CT transforms.

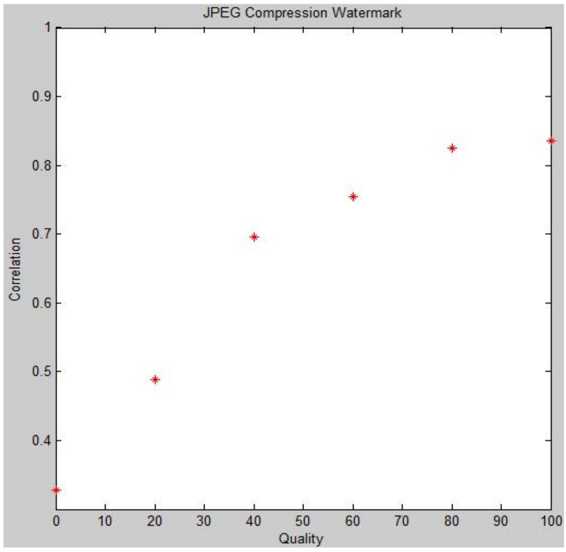

Fig. 15 Correlation due to JPEG compression attacks based on DWT-CT

Fig. 16 The attacked watermarked image by dithering based on DWT- CT

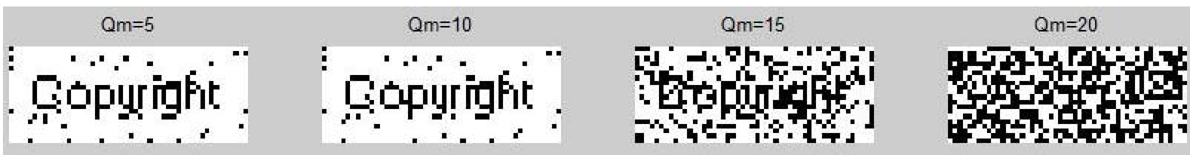

Fig. 17 The extracted watermark image after dithering based on DWT- CT

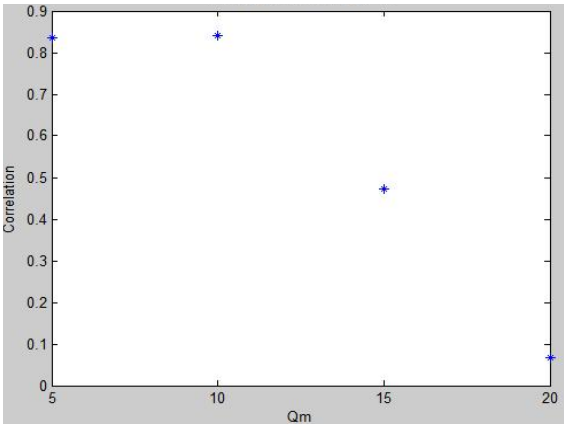

Fig. 18 Correlation due to dithering attacks based on DWT- CT

Table I shows the results of correlation between the original watermark and the watermark extracted from the attacked watermarked image by geometrical attacks: Rotation and cropping. After that we measure the robustness against the Watermark Removal Attacks: Gaussian Noise, JPEG Compression, and Dithering. Table II shows the results of Correlation between original watermark and the watermark extracted from the attacked watermarked image after apply removal attacks.

TABLE I
CORRELATION VALUES DUE TO GEOMETRICAL ATTACKS FOR DWT-CT

Algorithm	**Correlation**							
	Rotation Angle				**Cropping Block Size**			
	60	**120**	**240**	**300**	**8**	**104**	**152**	**200**
DWT-CT	0.028	-0.063	0.051	0.037	0.831	0.805	0.759	0.635

TABLE II
CORRELATION VALUES DUE TO REMOVAL ATTACKS FOR DWT-CT

Algorithm	**Correlation**								
	Gaussian Noise Mean			**Compression Quality**			**Dithering *Qm***		
	0	0.4	0.8	0	40	80	5	10	15
DWT-CT	0.835	0.838	0.835	0.327	0.695	0.825	0.835	0.841	0.472

V. DISCUSSION

Although most work in the field of digital image watermarking focuses on utilizing DWT due to its excellent spatial-frequency localization and multiresolution properties, which are similar to the theoretical models of human visual syste; there are two drawbacks associated with DWT. First, it lacks shift invariance, which means small shift in input signal that can cause big changes in the energy distribution of the wavelet coefficients. Second, the DWT has poor directional selectivity, which is evident from the impulse responses of the filters of the individual sub-bands. CT provides flexible multi-resolution representation of images. One of the unique properties of the CT is that we can specify the number of directional decompositions required at every level of multi-resolution pyramid [8]. The reason for applying the two transforms is based on the fact that combined transforms could compensate for the drawbacks of each other, resulting in effective watermarking. Although most work in the field of digital image watermarking focuses on utilizing DWT due to its excellent spatial-frequency localization and multiresolution properties; CT began to gain some interest for capability of capturing directional information such as smooth contours and directional edges [7]. So, the objective of this work to design an improved combined watermarking algorithm which is concerned with copyright protection for digital images using watermarking. The main requirements for an efficient digital image watermarking system are imperceptibility and robustness.

Table III shows the PSNR for 2-DWT, 3-CT and the combined DWT-CT.

TABLE III
PSNR VALUES FOR 2-DWT, 3-CT AND THE DWT-CT

Watermarked Image		
2-DWT	**3-CT**	**DWT-CT**
PSNR = 80.21	PSNR = 76.88	PSNR = 88.11

At the beginning, we tested the performance of applied 2-DWT and 3-CT algorithm separately for the sake of comparison before combining them. First, the results we obtained for the DWT algorithm only gave a PSNR value 80.21. Second, the results after applying CT algorithm only gave a PSNR value of 76.88. Finally, we evaluated the imperceptibility of the combined DWT-CT algorithm which gave a PSNR value of 88.11. The result of our combined algorithm shows better results in comparison with the best chosen sub-band in DWT and CT.

We compared the robustness of the three algorithms for different attacks. First we applied Geometrical Attacks: Rotation and Cropping. The results of Correlation values between the original watermark and the extracted watermark from the attacked watermarked image are shown in Table IV. Then we applied watermark removal attacks: Gaussian Noise, JPEG Compression and Dithering. The results of correlation values between the original watermark and the extracted watermark from the attacked watermarked image are shown in Tables V-VII.

TABLE IV
CORRELATION VALUES DUE TO ROTATION AND CROPPING ATTACKS IN THE 3 ALGORITHMS

Algorithm	Correlation							
	Rotation Angle				Cropping Block Size			
	60	120	240	300	8	104	152	200
2-DWT	0.031	0.041	0.0067	-0.021	0.691	0.664	0.591	0.526
2-CT	0.311	0.309	-0.303	-0.314	0.443	0.431	0.401	0.385
DWT-CT	0.028	-0.063	0.051	0.037	0.831	0.805	0.759	0.635

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TABLE V
CORRELATION VALUES DUE TO GAUSSIAN NOISE ATTACK IN THE 3 ALGORITHMS

Algorithm	Gaussian Noise Mean		
	0	0.04	0.08
2-DWT	0.698	0.698	0.698
2-CT	0.446	0.446	0.445
DWT-CT	0.835	0.838	0.835

TABLE VI
CORRELATION VALUES DUE TO COMPRESSION QUALITY ATTACK IN THE 3 ALGORITHMS

Algorithm	Compression Quality		
	0	40	80
2-DWT	0.380	0.695	0.695
2-CT	0.309	0.443	0.446
DWT-CT	0.327	0.695	0.825

TABLE VII
CORRELATION VALUES DUE TO DITHERING ATTACK IN THE 3 ALGORITHMS

Algorithm	Dithering Qm		
	5	10	15
2-DWT	0.700	0.702	0.465
2-CT	0.447	0.444	0.366
DWT-CT	0.835	0.841	0.472

Accordingly, the results of our improved system are compared to relevant works of others in the field of watermarking. Table VIII shows some comparative results of different methods of digital image watermarking.

Al-Haj [1] found that the combined DWT-DCT watermarking algorithm imperceptibility evaluation produced a PSNR value 97.072. In [11], Shilbayeh and Ashimary presented a new robust and secure hybrid watermark technique based on HWT and DWT. This method achieved a PSNR value 37.52 and robust to Invert and Gaussian noise. Amirgholipour and Naghsh-Nilchi [2] developed a new robust digital image watermarking algorithm based on join DWT-DCT transforms. It is clear from Table IV that our algorithm shows a significant improvement in imperceptibility compared to [2], Shilbayeh and Ashimary [11] and is more robust compared with all previous works.

TABLE VIII
EVALUATION RESULTS OF DIFFERENT RELATED WORKS OF DIGITAL IMAGE WATERMARK

References	Methodology	Imperceptibility	Robustness
Al-Haj [1]	Combined DWT-DCT Digit Image Watermarking	PSNR=97.072	Robust against Gaussian Noise and Cropping
Shilbayeh and Ashimary [11]	Cascading HWT-DWT Digit Image Watermarking	PSNR=37.52	Robust against Invert and Gaussian Noise
Amirgholipour and Naghsh-Nilchi [2]	Jointed DWT-DCT Digit Image Watermarking	PSNR=37.88	Robust against Gaussian Noise, Compression, Blurring, and Cropping
DWT-CT	Combined DWT-CT Digit Image Watermarking	PSNR=88.11	Robust against Gaussian Noise, Dithering, and cropping

VI. CONCLUSIONS

DWT and CT have been applied efficiently and successfully in many digital image watermarking systems. In this paper, we implemented and tested our algorithm of digital image watermarking based on combination between DWT and CT. Watermarking was done by embedding the watermark in the two level-DWT of original image followed by two level-CT on the carefully selected subband. The combination improves the system performance. The system was tested using five common types of image attacks. It achieved a PSNR value 88.11 and provided a high resistance to JPEG compression, Gaussian noise and dithering.

Compared with other existing watermarking systems, our system is more imperceptible and robust against Gaussian noise attack. Classical watermarking system is particularly compared based on DWT, using the same embedding strategy, the imperceptibility of the system is better than DWT only and stronger robustness than based on DWT only. So we reached our goal by implementing an efficient algorithm that does not degrade the visibility of original image.

In the future work, the algorithm can be improved to choose the best gain factor which compromises tradeoff between imperceptibility and robustness.

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