Combined DWT-CT Blind Digital Image Watermarking Algorithm

Nidal F. Shilbayeh, Belal AbuHaija, and Zainab N. Al-Qudsy

***Abstract*—**In this paper, we propose a new robust and secure system that is based on the combination between two different transforms Discrete wavelet Transform (DWT) and Contourlet Transform (CT). The combined transforms will compensate the drawback of using each transform separately. The proposed algorithm has been designed, implemented and tested successfully. The experimental results showed that selecting the best sub-band for embedding from both transforms will improve the imperceptibility and robustness of the new combined algorithm. The evaluated imperceptibility of the combined DWT-CT algorithm which gave a PSNR value 88.11 and the combination DWT-CT algorithm improves robustness since it produced better robust against Gaussian noise attack. In addition to that, the implemented system shored a successful extraction method to extract watermark efficiently.

***Keywords*—**DWT, CT, Digital Image Watermarking, Copyright Protection.

I. Introduction

TODAY all users of the internet have the ability to download duplicate and retransmit the multimedia data legally or illegally due to the internet open environment. Many problems arise such as copyright protection and intellectual property. Digital watermarking is one of the possible solutions to solve such a problem. Digital watermarking is a process of hiding secret information called a watermark in original multimedia objects such as digital image, text document, audio and video clips.

Any digital image watermarking system can be divided into two main subsystems but complimentary to each other: embedding subsystem and extracting subsystem. In embedding subsystem, the watermark is hidden in the original image to obtain watermarked image, and to measure imperceptibility. In extracting subsystem, the output of embedding subsystem (watermarked image) is the input, and the watermark is the extracted, and to measure robustness. Researchers in the field of digital watermarking search on effective techniques provide two properties: imperceptibility (watermark not noticeable by viewer), and robustness against attacks that try to remove or destroy watermark.

The watermark algorithm can be divided into two types according to whether the original image is required to extract the watermark: blind and non-blind. Blind algorithm does not need the original image in extraction while, non-blind algorithm needs the original image to extract watermark.

Digital image watermarking utilizes many types of transforms such as Discrete Wavelet Transform (DWT) [3], Discrete Cosine Transform (DCT) and Contourlet Transform (CT) [4], [5], [8], [10]. The reason of applying two transforms is based on the fact that the combined transform, could make up for the disadvantages of each other, so that effective watermarking approaches could acquire [2].

DWT has been used in digital image watermarking more frequently due to its excellent spatial localization and multiresolution characteristics, which are similar to the theoretical models of the human visual system [1]. DWT performance is increased by combining it with another transform [6], [9], [11].

CT has been developed as an improvement over wavelet. In addition to multiscale and time frequency localization prosperities of wavelet, CT has the capability of capturing directional information such as smooth contours and directional edges. So that, CT is well suited for images like maps were a lot of curves and text are present.

In this paper, a new suggested blind digital image watermarking algorithm based on combining DWT and CT is introduced and implemented.

II. Related Works

Digital Image watermarking is the image processing field that is severely considered in the last few years due to rapid development in the digital multimedia technologies. In this section we illustrate several related works in order to determine the major research techniques and methodologies used. In the following literature survey describes the previous work done on digital watermarking:

Reference [4] introduces a new image decomposition scheme called CT which is more effective in representing smooth contours in different directions of an image than DWT.

Reference [6] proposes a new watermarking algorithm using DWT prior to the DCT to provide better imperceptibility in harmony with the human visual system. Their algorithm showed resistance to common signal processing operation.

Reference [8] proposes a new method of non-blind digital image watermarking in contourlet domain. In this method the number of directions in the band pass image is doubled at every other scale of decomposition according to curve scale

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relation and the simulation results which prove that contourlet domain watermarking is well suited for image like maps where a lot of curves and texts are inherently present.

Reference [1] describes imperceptible and robust combined DWT-DCT digital image watermarking algorithm and the performance evaluation result shows that combining the two transform improves the performance of the watermarking algorithm that are based solely on the DWT transform.

Reference [5] investigates the role of CT versus DWT in providing robust image watermarking. Two measures are utilized in the comparison between wavelet based and contourlet based methods, peak signal to noise ratio (PSNR) and normalized cross correlation (NCC).

Reference [9] proposes an algorithm of digital image watermarking based on DCT and DWT according to the characteristics of the human vision. In their algorithm the information of the digital watermark is transform using DCT embedded in the original image which is transform using DWT then embedding information of the digital watermark in the high frequency band of the original image transformation.

Reference [2] proposes a new robust digital image watermarking algorithm based on join DWT-DCT transforms. A binary watermarked logo is scrambled by Arnold cat map and embedded in the certain coefficient sets of a 3-level DWT transformed of a host image. Then, DCT of each selected DWT subband is computed and the PN-sequences of the watermark bits are embedded in the middle frequencies coefficient of the corresponding DCT block.

Reference [7] clarifies the advantages by CT versus the DWT. Prove that the Contourlet domain is suitable for image like maps.

Reference [11] presents a new robust and secure hybrid watermark technique based on HWT and DWT. The proposed method is constructed by cascading two different but complementary techniques. Performance evaluation of the proposed method showed improved result of imperceptibility, robust and security in comparison with other systems.

III. The Proposed Combined DWT-CT Digital Watermarking Algorithm

In this paper, we proposes a new image watermarking algorithm based on combining two transforms; DWT and CT. Watermarking is done by modifying the coefficients of carefully selected DWT sub-band, followed by applying CT on the selected sub-band. 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.

There are different techniques that can be used to embed the watermark, but since using the spatial domain gives us fragile watermarks that are not robust against the attacks, we decided to work on the frequency domain because we are searching for watermarking algorithms that are robust against different kinds of attacks such the Geometrical and Removal attacks, without affecting the quality of the watermarked image, so we were trying to solve the conflict between robustness and imperceptibility.

Fig. 1 shows the sequence of the techniques we used in our algorithm.

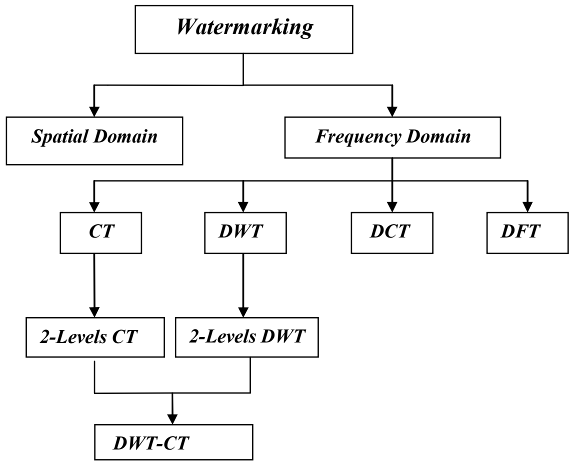


Fig. 1 Watermarking Techniques Used

A new image watermarking algorithm will be presented by combining DWT and CT to develop a blind image watermarking algorithm to provide better imperceptibility and higher robustness against variety of attacks. First, we applied a 2-level DWT to the image by choosing mid-mid sub-band. The selection to the mid-mid subband shored better results in imperceptibility. Second, we applied CT to the chosen subband to study their effects.

The main reason of combing DWT and CT is to minimize the drawbacks of each of them separately. Most researchers in the field of digital watermarking focuses on using DWT due to its excellent spatial localization and multi-resolution properties, which are similar to the theoretical models of human visual system. However, 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. Fig. 2 shows Lena’s image after applying 2-level DWT followed by 2-level CT.

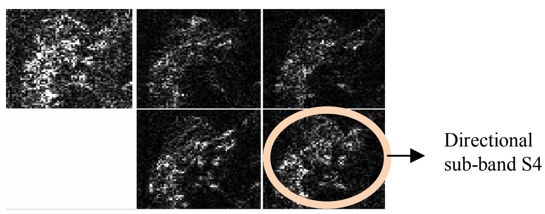


Fig. 2 2-Level DWT followed by 2-Level CT

The Combined DWT-CT Based watermarking Algorithm consists of two algorithms; watermark embedding and watermark extraction.

A. Embedding Algorithm Based on DWT-CT

The watermark embedding algorithm is shown as block diagram in Fig. 3 and described in details in the following steps.

Step 1. Apply DWT to decompose the original image into four non-overlapping multi-resolution sub-bands:LL1, HL1, LH1, and HH1.

Step 2. Apply DWT again to HL1 to get four smaller sub-bands and choose the HL2 sub-band for further decomposition using CT.

Step 3. Apply 2-level CT to selected sub-bands in step 2. Then select directional sub-bands to embed the watermark on it.

Step 4. Re-formulate the gray-scale watermark image into a vector of zeros and ones.

Step 5. Generate uncorrelated pseudorandom sequence (pn_sequence) that will be used in embedding the watermark bit 0. Size of (pn_sequence) must be equal to the size of the chosen sub-band.

Step 6. Modify the coefficients of the chosen sub-band by embedding pn_sequence with the gain factor k according to the equation:

$$X=X+K* pn\_sequance$$

where X is the coefficient of the selected sub-band and k is the gain factor .We should find a suitable gain factor which gives the best tradeoff between visibility and robustness.

Step 7. Perform ICT using the selected sub-bands of each level followed by performed IDWT and modified coefficient to produce the watermarked image.

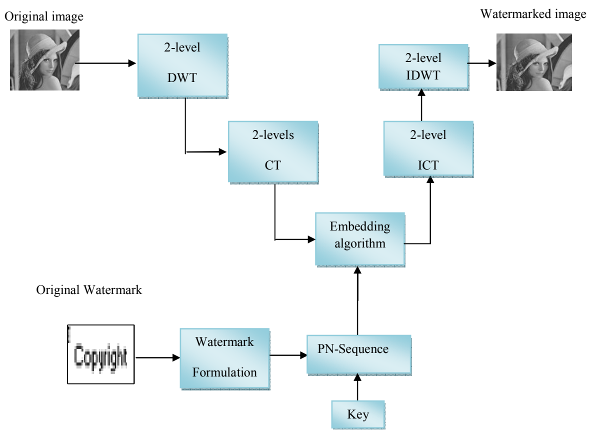


Fig. 3 DWT-CT Watermark Embedding Block Diagram

B. Extracting Algorithm Based on DWT-CT

The DWT-CT watermark algorithm is a blind watermarking algorithm, and thus the extraction does not need the original image. The watermark extraction algorithm is shown in Fig. 4, and described in detail in the following steps:

Step 1. Apply DWT to decompose the watermarked image which is obtained from the embedding algorithm to get four non-overlapping multi-resolution sub-bands: LL1, HL1, LH1, and HH1.

Step 2. Apply DWT again to HL1 to get four smaller sub-bands and select the HL2 sub-band for further decomposition by applying CT.

Step 3. Apply 2-level CT to the selected sub-bands in step 2. Select directional sub-bands to embed the watermark on it.

Step 4. Re-formulate the gray-scale watermark image into a vector of zeros and ones.

Step 5. Generate uncorrelated pseudorandom sequence (pn_sequence) using the same seed used in the watermark embedding algorithm.

Step 6. Calculate the correlation of the chosen sub-band with the generated pseudorandom sequence by m times, where m is the length of watermark vector.

Step 7. Calculate the mean of the correlation and compare it with each value of the correlation value that we calculated in step 6.

Step 8. If the calculated values of the correlation are greater than the mean, then the extracted watermark is equals 0, otherwise 1.

Step 9. Reconstruct the watermark using the extracted watermark bits, and then compute the similarity between the original and extracted watermark.

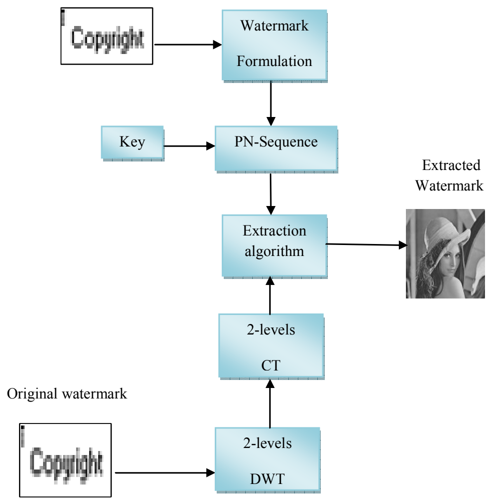


Fig. 4 DWT-CT Watermark Extraction Block Diagram

IV. Experimental Results

The performance of the watermarking algorithm is usually evaluated with respect to two properties: imperceptibility and robustness. In each section, the implementation of the algorithm is evaluated by using two measures: Peak Signal to Noise Ratio (PSNR) which measures imperceptibility and the Normalized Cross Correlation (NCC) which measures robustness.

A. Imperceptibility

The watermark signal should be imperceptible (visible) to the end user who is viewing the watermarked image. This means that the perceived quality of the image should not be distorted by the presence of the watermark and a user should not be able to differentiate between watermarked and original image.

As a measure of the quality of a watermarked image, Peak Signal to Noise Ratio (PSNR) is used.

To compute the Peak signal to noise ratio, first we need to compute the Mean Square Error (MSE) as in (1) [1]:

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

where I is the original image, K is the watermarked image that contain m by n pixels,

PSNR calculated according to (2):

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

Here, MAX1 is the maximum pixel value of the image. Once the PSNR exceeds some value, the errors become undetectable to human viewers. Conversely, the human visual system seems to have a saturation effect as well. Once the image quality falls below a certain level, the image simply looks bad.

The combined DWT-CT algorithm has been tested and evaluated. Also, DWT and CT algorithms has been tested and evaluated separately for the sake of comparison. The performance of the watermarking algorithm is evaluated with respect to the imperceptibility property. The implementation of each algorithm is evaluated using Peak Signal to Noise Ratio (PSNR) which measures imperceptibility.

As a sample watermark, we choose the Image shown in Fig. 5. The size of this image is 50x20. We used the “Lena” image shown in Fig. 6 as the original image in which we embedded the watermark. The size of this image is 512x512.

Fig. 5 Sample Watermark

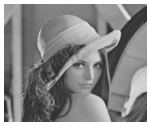


Fig. 6 Original Image

B. Searching for the Best Sub-Band in DWT and CT Embedding Algorithms Perceptibility

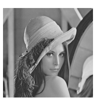
We carried out the watermark embedding algorithm based on DWT domain only. Applied 1-level DWT of the Lena image produced 256×256 sub-bands: LL1, LH1, HL1, and HH1. Since embedding the watermark beyond the watermark in LH2 or HH2 is more effective. The coefficient of the LH2 or HH2 sub-band is selected for embedding process. We evaluate the imperceptibility of the DWT algorithm by measuring PSNR for different sub-bands as shown in Table I.

TABLE I
PSNR VALUES AT DIFFERENT DWT SUB-BANDS

Original image	**Watermarked image**					
	1-DWT (LH_1)	1-DWT (HH_1)	2-DWT (LH_2)	2-DWT (HH_2)	3-DWT (LH_3)	3-DWT (HH_3)
						
	PSNR=71.28	PSNR=71.28	PSNR=80.21	PSNR=77.12	PSNR=83.26	PSNR=100.97

The imperceptibility of CT was tested by calculating the PSNR between the original image and the watermarked image. We embedded the watermark image in each sub-band after applying 1-level CT. Then we calculate the imperceptibility of this algorithm with the 2 and 3 levels CT. We noticed that any change in the low frequency affected the imperceptibility of the image. In Table II we compared the results obtained from embedded watermark image in different sub-bands of 1, 2, and 3 levels CT.

TABLE II
PSNR VALUES AT DIFFERENT CT SUBBANDS

Original image	**Watermarked image**								
	1-CT Sub 0	1-CT Sub 1	1-CT Sub 2	2-CT Sub 0	2-CT Sub 1	2-CT Sub2	2-CT Sub3	2-CT Sub 4	3-CT Sub 8
									
	PSNR= 70.62	PSNR= 69.22	PSNR= 69.93	PSNR= 70.60	PSNR= 72.41	PSNR= 71.41	PSNR= 72.16	PSNR= 73.21	PSNR= 76.88

We notice that best choice of embedding is 3-level in directional sub-band since it produced better result in imperceptibility and we continued the work on 3-level CT.

Fig. 7 shows the imperceptibility of the DWT-CT algorithm was tested in our implemented GUI system according to the best tested sub-bands in DWT and CT. When embedding in the Mid-Mid sub-band of 2-level DWT followed by apply 2-level CT. The watermarked image has the PSNR value equal to 88.112.

Fig. 7 Watermarking GUI after performing the steps mentioned above

C. Robustness

Testing the robustness of the combined DWT-CT algorithm is done by adding an attack to watermarked images such as the Gaussian noise. The performance of the watermark extraction is measured by the NCC value. The effect of each one of these attacks is presented below:

1. Effect of Gaussian Noise

For adding the Gaussian noise to the watermarked image, we fixed the value of the variance at zero and changed the mean. When the 2-levels DWT are followed by applying 2-levels CT and directional sub-band was chosen to embed the watermark in, the attacked watermarked image at different values of the mean is shown in Fig. 8 and the extracted watermark and the correlation values between the original and the extracted watermark at different values of the mean are shown in Figs. 9 and 10 respectively.

Fig. 8 The Attacked Watermarked Image by noise based on DWT-CT

Fig. 9 The Extracted Watermark Image after noise based on DWT- CT

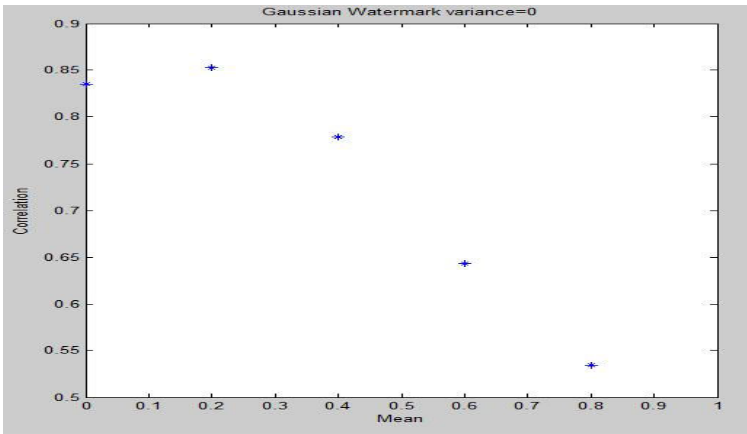


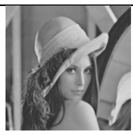
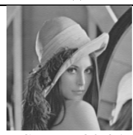
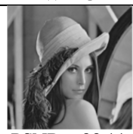
Fig. 10 Correlation due to noise attacks based on DWT-CT

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 system. However, 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 COMBINED DWT-CT

Original Image	**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 76.88. Finally, we evaluated the imperceptibility of the combined DWT-CT algorithm which gave a PSNR value 88.11. The result of our combined algorithm shows better results in comparison with the best chosen sub-band in DWT and CT.

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

Reference [1] found that the combined DWT-DCT watermarking algorithm imperceptibility evaluation produced a PSNR value 97.072. Reference [11] presented a new robust and secure hybrid watermark technique based on HWT and DWT. This method achieved a PSNR value 37.52. Reference [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], [11].

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

References	Methodology	Imperceptibility
[1]	Combined DWT-DCT Digit Image Watermarking	PSNR=97.072
[11]	Cascading HWT-DWT Digit Image Watermarking	PSNR=37.52
[2]	Jointed DWT-DCT Digit Image Watermarking	PSNR=37.88
DWT-CT	Combined DWT-CT Digit Image Watermarking	PSNR=88.11

We compared the robustness of the three algorithms for Gaussian Noise attack. The results of correlation values between the original watermark and the extracted watermark from the attacked watermarked image are shown in Table V.

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

VI. CONCLUSIONS

Discrete Wavelet Transform (DWT) and Contourlet Transform (CT) have been applied efficiently and successfully in many digital image watermarking systems. In this paper, we introduce a new efficient 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 evaluated imperceptibility of the combined DWT-CT algorithm which gave a PSNR value 88.11 and the combination DWT-CT algorithm improves robustness since it produced better robust against Gaussian noise attack.

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. So we reached our goal by implementing an efficient algorithm that doesn't degrade the visibility of original image.

Robustness against several attacks such as rotation, dithering, cropping, and compression will be presented in future work. In addition to that, an algorithm can be implemented to choose the best gain factor which compromises tradeoff between imperceptibility and robustness.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support for this work from IT Research Center for the Holy Quran and its Sciences (NOOR), Taibah University, Madinah, Saudi Arabia.

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