Robust digital image watermarking based on joint DWT-DCT

Article *in* International Journal of Digital Content Technology and its Applications · January 2009

DOI: 10.4156/jdcta.vol3.issue2.amirgholipour · Source: DBLP

2 authors:


Saeed Amirgholipour Kasmani
Jaypee University of Information Technology


Ahmad Reza Naghsh-Nilchi
University of Isfahan

Robust Digital Image Watermarking Based on Joint DWT-DCT

Saeed K. Amirgholipour *Corresponding author , Ahmad R. Naghsh-Nilchi,
Computer Engineering Dept, University of Isfahan, IRAN
s.kasmani@Gmail.com, nilchi@eng.ui.ac.ir
doi: 10.4156/jdcta.vol3.issue2.amirgholipour

Abstract

In this paper, a new robust digital image watermarking algorithm based on Joint DWT-DCT Transformation is proposed. A binary watermarked logo is scrambled by Arnold cat map and embedded in certain coefficient sets of a 3-level DWT transformed of a host image. Then, DCT transform of each selected DWT sub-band is computed and the PN-sequences of the watermark bits are embedded in the middle frequencies coefficients of the corresponding DCT block. In extraction procedure, the watermarked image, which maybe attacked, is pre-filtered by combination of sharpening and Laplassian of Gaussian filters to increase distinction between host image and watermark information. Subsequently, the same procedures as the embedding process is used to extract the DCT middle frequencies of each sub-band. Finally, correlation between mid-band coefficients and PN-sequences is calculated to determine watermarked bits. Experimental results show that high imperceptibility is provided as well as higher robustness against common signal processing attacks. In compare to current watermarking algorithms which are based on the joint of DWT-DCT, proposed system is achieved significantly higher robustness against enhancement and noise addition attacks.

Keywords

Digital image watermarking, Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), Arnold Cat Map, Unsharp Filter, Laplassian of Gaussian Filter (LoG)

1. Introduction

The fast development of the Internet in recent years has made it possible to easily create, copy, transmit, and distribute digital data. Consequently, this has led to a strong demand for reliable and secure copyright protection techniques for digital data. Digital watermarking has been proposed as valid solution for this problem. The purpose of the watermark is to embed some additional information about the digital data without visibly modifying it.

In order to be successful, the watermark should be invisible and robust to premeditated or spontaneous modification of the image. It should be robust against common image processing operations such as filtering, additive noise, resizing, cropping etc and common image compression techniques. If the watermark is placed in perceptually significant coefficients of the image, the robustness against image distortion is better achieved. These coefficients do not change much after common image processing and compression operations. Also, if these coefficients are destroyed, the reconstructed image is different from the original image and the digital watermark become irrelevant. Although, embedding the watermark in perceptually significant coefficients could alter the perceived visual quality of the image. Thus, two essential prerequisites for a powerful watermarking scheme, robustness and invisibility conflict with each other [1].

Watermarking techniques can be categorized in different ways. They can be classified according to the type of watermark being used, i.e., the watermark may be a visually recognizable logo or a sequence of random numbers. Another classification is based on domain which the watermark is applied i.e., the spatial domain or the transform domain. The earlier watermarking techniques were almost in spatial domain. Spatial domain techniques are not resistant enough to image compression and other image processing [2]. Transform domain watermarking schemes like those based on the discrete cosine transform (DCT) [3, 4, 5], the discrete wavelet transform (DWT) [6, 7, 8] typically provide higher image imperceptibility and are much more robust to image manipulations. In these domain watermark is placed in perceptually significant coefficients of the image. However, DWT [9] has been used more frequently in digital image watermarking due to its time/frequency decomposition characteristics, which resemble to the theoretical models of the human visual system [10].

In order to further performance improvements in DWT-based digital image watermarking algorithms could be obtained by jointing DWT with DCT [11]. The reason of applying two transform is based on the fact that jointed transform could make up for the disadvantages of each other, so that effective watermarking approaches could acquire.

Fotopoulos and Skodras [12] decompose the original image into four bands using the Haar wavelet, and then perform DCT on each of the bands; the watermark is embedded into the DCT coefficients of each band. Serkan Emek and Melih Pazarci [13] compared image dependent and additive blind watermarking algorithms that embed a watermark in the DWT-DCT domain by taking the properties of the HVS into account [14]. The image dependent algorithm modulates the watermarking coefficients with original mid-frequency DWT-DCT coefficients [15]. Ali Al-Haj[16] described a combined DWT-DCT digital image watermarking algorithm that embed the watermark in the first and second level of DWT coefficient sets of the host image, followed by the application of DCT on the selected DWT coefficient sets.

However, robustness of common DWT and DCT transform methods is increased by previous hybrid method; despite, their robustness against noise and blurring attack is not acceptable. In order to solve this problem, a new image watermarking algorithm based on jointed DWT-DCT method is presented in this paper. In proposed method, Watermarking is done by altering the wavelets coefficients of middle frequency coefficient sets of 3-levels DWT transformed host image, followed by the application of the DCT transform on the selected coefficient sets. Difference between Al-Haj's method and proposed is in selection of sub-band for embedding watermark and novel pre-processing before extraction procedure. Al-Haj chosen HL sub-band in 2-level dwt transformed to performing block DCT on them, But proposed method use all of the HL frequency sub-band in the middle frequency coefficient sets LHx and HLx in 3-levels DWT transformed image. By this algorithm, coarser level of DWT in terms of imperceptibility and robustness is chosen to apply 4×4 block-based DCT on them, and consequently higher imperceptibility and robustness can be achieved. Also, pre-filtering operation is used before extraction of the watermark, sharpening and Laplacian of Gaussian (LoG) filtering, is used to increase different between information of watermark and hosted image.

The rest of this paper is organized as follows. In section 2, we introduce the two transforms briefly. Section 3 describes the embedding algorithm in detail. The extraction algorithm is described in Section 4. Section 5 presents the experimental results to demonstrate the performance of this scheme. The conclusion is drawn in Section 6.

2. Common Frequency Domain Method (DWT and DCT)

The DCT and DWT transforms have been widely used in many digital watermarking applications. In this section, we introduce the two transforms briefly, and outline their relatedness to the implementation of digital watermarking.

2.1. The DCT Transform

The discrete cosine transforms is a technique for converting a signal into elementary frequency components [11]. It represents an image as a sum of sinusoids of varying magnitudes and frequencies. With an input image, x, the DCT coefficients for the transformed output image, y, are computed according to Equation.1 shown below. In the equation, x, is the input image having N x M pixels, x (m, n) is the intensity of the pixel in row m and column n of the image, and y (u, v) is the DCT coefficient in row u and column v of the DCT matrix.

$$y(u,v)=\sqrt{\frac{2}{M}}\sqrt{\frac{2}{N}}\alpha_m\alpha_n\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\{x(m,n) \times\cos\frac{(2m+1)u\Pi}{2M}\cos\frac{(2n+1)u\Pi}{2N}\} \quad (1)$$

Where

$$\alpha_u=\begin{cases}\frac{1}{\sqrt{2}} & u=0\\ 1 & u=1,2,...,M-1\end{cases}$$

$$\alpha_v=\begin{cases}\frac{1}{\sqrt{2}} & v=0\\ 1 & v=1,2,...,N-1\end{cases}$$

The image is reconstructed by applying inverse DCT operation according to Equation. 2:

$$x(m,n)=\sqrt{\frac{2}{M}}\sqrt{\frac{2}{N}}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1}\{\alpha_m\alpha_n y(u,v) \times\cos\frac{(2m+1)u\Pi}{2M}\cos\frac{(2n+1)u\Pi}{2N}\} \quad (2)$$

The popular block-based DCT transform segments image non-overlapping blocks and applies DCT to each block. This results in giving three frequency coefficient sets: low frequency sub-band, mid-frequency-sub-band and high frequency sub-band. DCT-based watermarking is based on two facts. The first fact is that much of the signal energy lies at low-frequencies sub-band which contains the most important visual parts of the image. The second fact is that high frequency components of the image are usually removed through compression and noise attacks. The watermark is therefore embedded by modifying the coefficients of the middle frequency sub-band so that the visibility of the image will not be affected and the watermark will not be removed by compression [16].

2.2. The DWT Transform

Wavelet transform decomposes an image into a set of band limited components which can be reassembled to reconstruct the original image without error. Since the bandwidth of the resulting coefficient sets is smaller than that of the original image, the coefficient sets can be down sampled without loss of information. Reconstruction of the original signal is accomplished by up sampling, filtering and summing the individual sub bands. For 2-D images, applying DWT corresponds to processing the image by 2-D filters in each dimension. The filters divide the input image into four non-overlapping multi-resolution coefficient sets, a lower resolution approximation image (LL1) as well as horizontal (HL1), vertical (LH1) and diagonal (HH1) detail components. The sub-band LL1 represents the coarse-scale DWT coefficients while the coefficient sets LH1, HL1 and HH1 represent the fine-scale of DWT coefficients. To obtain the next coarser scale of wavelet coefficients, the sub-band LL1 is further processed until some final scale N is reached. When N is reached we will have 3N+1 coefficient sets consisting of the multi-resolution coefficient sets LLN and LHX, HLX and HHX where x ranges from 1 until N.

Due to its excellent spatio-frequency localization properties, the DWT is very suitable to identify the areas in the host image where a watermark can be embedded effectively. In particular, this property allows the exploitation of the masking effect of the human visual system such that if a DWT coefficient is modified, only the region corresponding to that coefficient will be modified. In general most of the image energy is concentrated at the lower frequency coefficient sets LLx and therefore embedding watermarks in these coefficient sets may degrade the image significantly. Embedding in the low frequency coefficient sets, however, could increase robustness significantly. On the other hand, the high frequency coefficient sets HHx include the edges and textures of the image and the human eye is not generally sensitive to changes in such coefficient sets. This allows the watermark to be embedded without being perceived by the human eye. The agreement adopted by many DWT-based watermarking methods, is to embed the watermark in the middle frequency coefficient sets HL_X and LH_X is better in perspective of imperceptibility and robustness [16].

3. Embedding Algorithm

The main strength offered by transform domain techniques is that they can take advantage of special properties of alternate domains to address the limitations of spatial domain or to support additional features. The purpose of this paper is to use joint of the wavelet and cosine transform to embed watermark information in most robust and imperceptible part of image. The wavelet transform has a number of advantages over the other transforms, namely the DCT: The DWT is a multi-resolution description of an image: the decoding can be processed sequentially from low resolution to higher resolutions. The DWT is closer to human visual system than DCT. Hence, the artifacts introduced by wavelet domain coding with high compression ratio are less annoying than those introduced at the same bit rate by DCT.

In the propose method, we take these benefit of DWT to chose the most proper sub-bands in case of robustness and imperceptibility. Then, the block based DCT is applied on these selected band to embed watermark in middle frequencies of each block to augment further robustness of watermarked image against different attacks. In fact with utilizing joint of the two common frequency methods, we could take the advantageous of both two algorithms to increase robustness and imperceptibility. At the same time, we could suppress the effect of attack that designed for each of these frequency methods such as jpeg and jpeg2000 compression.

This algorithm has been implemented in MATLAB 7 using the wavelet, image processing and statistic toolboxes, and XnView and Photoshop image editing software.

3.1. Watermark Scramble

The embedded watermark in the algorithm is not a traditional one dimension pseudo-random sequence, but a meaningful two value image. The watermark in this paper is scrambled firstly in order to guarantee the embedded watermark against clipping, re-sampling and so on and improve the watermark's robustness.

Image scrambling is using some algorithm to scramble every pixel in one image, but the sum of

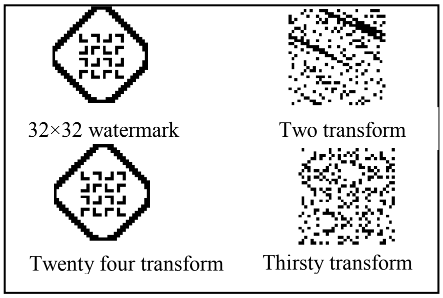


Figure 1. The Scrambled watermark logo

pixels is invariable. Because watermark scrambling can eliminate watermark's pixels of spacing relativity, the watermark's robustness against image clipping operation will be improved. After the watermark processed by scrambling algorithm, even if some attacker can detect the watermark signal, he cannot recover the original watermark without the scrambling algorithm. Even if achieving the scrambling algorithm, he still does a great deal of test to recover the original watermark. In this way, the watermark of secrecy and security can be strengthened further. Image scrambling methods proposed already are Fass curve, Gray code, Arnold transform and magic square method and so on. In this paper, Arnold transform is chosen as pretreatment method for watermark signal. This method is intuitionistic, simple, periodic and easy to use.

Arnold transform [17] is that Arnold proposed a kind of transform in the traversing theory, called as Arnold's cat mapping. Assumed to draw a cat's face in plane unit square, Arnold's cat mapping is defined as equation .3:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \left[\begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \right] \bmod 1 \qquad (3)$$

Through mapping, cat's face image become from clear to blurry. In fact, this is the pixels' position removing, and this algorithm is mapping one by one.

From point of view of sample theory, digital image can be seeing as a two dimension discrete point array sampled according to certain interval and certain strategy in the two dimension continuous surface, that is to say, a image array. For digital square image, discrete Arnold mapping can be done as equation .4:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \left[\begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \right] \bmod N \qquad (4)$$

Every pixel in the image is transformed using above formula. After traversing all of pixels in the image, a scrambled image will be gained. In addition, transforming repeatedly for the image can generate different results until reaching the requirement. 32×32 watermark scrambled logos are showed as Figure 1. Because of Arnold transform of periodicity, the original image will be recovered [18].

3.2. Embedding Algorithm

The main strength offered by transform domain techniques is that they can take advantage of special properties of alternate domains to address the limitations of spatial domain or to support additional features. Watermarking process is started by applying 3-leveles DWT on the host image. The agreement adopted by many DWT-based watermarking methods is to embed the watermark in the middle frequency sub-bands HL_x and LH_x is better in perspective of imperceptibility and robustness.

Consequently, HL_x coefficient sets in level three is chosen to make to increase the robustness of our watermark against common watermarking attack, specially adding noise and blurring attacks, at little to no additional impact on image quality. Then, the block base DCT is performed on these selected DWT coefficient sets and embed pseudorandom sequences in middle frequencies. The watermark embedding procedure is represented in Figure 2 followed by a detailed explanation.

Step 1: Perform DWT on the host image to decompose it into four non-overlapping multi-resolution coefficient sets: LL_1, HL_1, LH_1 and HH_1.

Step 2: Perform DWT again on two HL_1 and LH_1 coefficient sets to get eight smaller coefficient sets and choose four coefficient sets: HL_{12}, LH_{12}, HL_{22} and LH_{22} as shown in Figure 3(a).

Step 3: Perform DWT again on four coefficient sets: HL_{12}, LH_{12}, HL_{22} and LH_{22} to get sixteen smaller Coefficient sets and choose four coefficient sets: HL_{13}, LH_{13}, HL_{23} and LH_{23}as shown in Figure 3 (b).

Step 4: Divide four coefficient sets: HL_{13}, LH_{13}, HL_{23} and LH_{23} into 4 x 4 blocks.

Step 5: Perform DCT to each block in the chosen coefficient sets (HL_{13}, LH_{13}, HL_{23} and LH_{23}). These coefficients sets are chosen to inquire both of imperceptibility and robustness of algorithms equally.

Step 6: scramble the watermark signal with Arnold algorithm for key times and gain the scrambled watermark Ws (i , j), key times can be see as secret key.

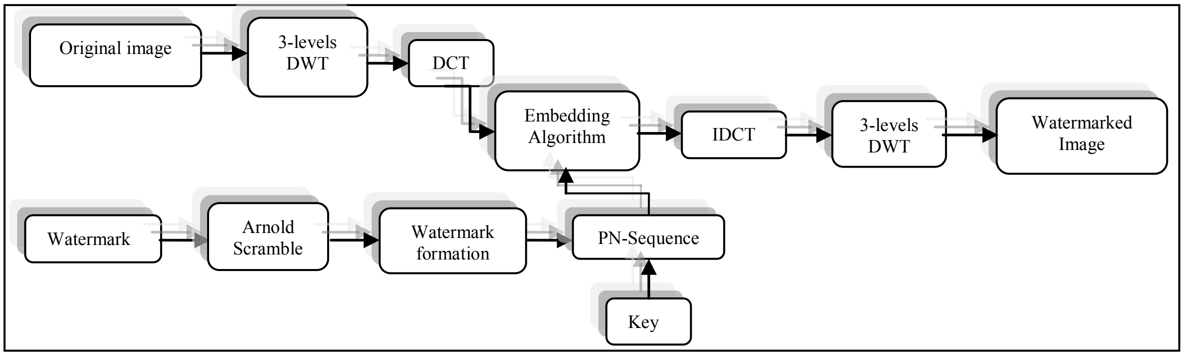
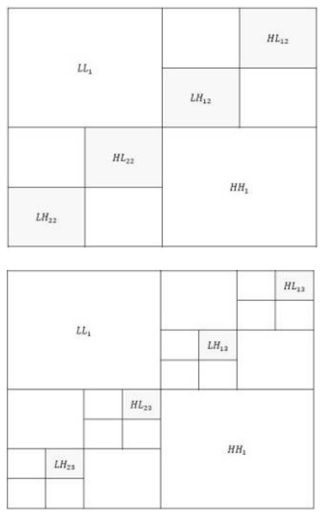


Figure 2. Joint DWT-DCT watermark embedding procedure



(a)

(b)

Figure 3. (a) Four multi-resolution DWT coefficient sets of the original image in level 2 to apply DWT to another level; (b) four selected multi-resolution DWT coefficient sets of the host image in level 3.

Step 7: Re-formulate the scramble watermark image into a vector of zeros and ones.

Step 8: Generate two uncorrelated pseudorandom sequences by a key. One sequence is used to embed the watermark bit 0 (PN_0) and the other sequence is used to embed the watermark bit 1 (PN_1). Number of elements in each of the two pseudorandom sequences must be equal to the number of mid-band elements of the DCT-transformed, DWT coefficient sets.

Step 9: Embed the two pseudorandom sequences, PN_0 and PN_1, with a gain factor α in the DCT transformed 4x4 blocks of the selected, DWT coefficient sets of the host image. Instead of embedding in all coefficients of the DCT block, it applied only to the mid-band DCT coefficients. If we donate X as the matrix of the mid-band coefficients of the DCT transformed block, then embedding is done as equation5:

$$X' = \begin{cases} X + \alpha * PN0 & watermark\_bit = 0 \\ X + \alpha * PN1 & watermark\_bit = 1 \end{cases} \qquad (5)$$

Step 10: Perform inverse DCT (IDCT) on each block after its mid-band coefficients have been modified to embed the watermark bits as described in the previous step.

Step 11: Perform the inverse DWT (IDWT) on the DWT transformed image, including the modified coefficient sets, to produce the watermarked host image.

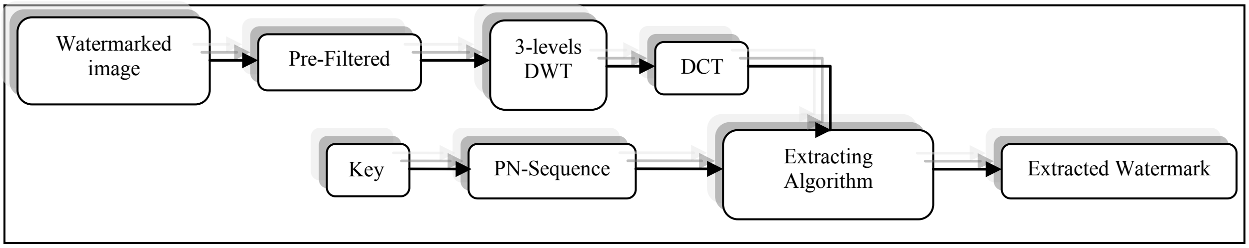


Figure 4. Jointed DWT-DCT watermark extraction procedure.

4. Extracting Procedure

The joint DWT-DCT algorithm is a blind watermarking algorithm, and thus the original host image is not required to extract the watermark. Execration algorithm is the same as embedding one, and pre-filtering is used before applying DWT transform to better separate watermark information from host image. The watermark extraction procedure is shown in Figure 4 and described in details in the following steps.

Step 1: perform combination of two filters as pre-filtering operation.

First filter is 3×3 spatial sharpening filter which is defined as equation 6:

$$\begin{matrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{matrix} \qquad (6)$$

This filter enhances contrast of watermarked image. And, second filter is Laplacian of Gaussian filter (LoG). This filter is designed by the equations 7 and 8:

$$h_g(n_1, n_2) = e^{-\frac{n_1^2 + n_2^2}{2\sigma^2}} \qquad (7)$$

$$h(n_1, n_2) = \frac{n_1^2 + n_2^2 - 2\sigma^2}{2\pi\sigma^6 \sum_{n_1} \sum_{n_2} h_g} \qquad (8)$$

In these equation n1 and n2 is the number of rows and columns in filter. The default value for them in h is 5 and 0.6 for σ.

Applying these two filters on watermarked image (that maybe attacked) could caused details of image become more manifest, its means that watermark information which is different from image background become recognizable straightforwardly. Combination of these two filters is helped to concentrate on finding information of watermark by degrading effect of none watermarked part of watermarked image and increasing watermarked part of it.

Step 2: Perform DWT on the pre-filtered watermarked image to decompose it into four non-overlapping multi-resolution coefficient sets: LL_1, HL_1, LH_1 and HH_1.

Step 3: Perform DWT again on two coefficient sets HL_1 and LH_1 to get eight smaller coefficient sets and choose four coefficient sets: HL_{12}, LH_{12}, HL_{22} and LH_{22} as shown in Figure 3(a).

Step 4: Perform DWT again on four coefficient sets: HL_{12}, LH_{12}, HL_{22} and LH_{22} to get sixteen smaller coefficient sets and choose four coefficient sets: HL_{13}, LH_{13}, HL_{23} and LH_{23} as shown in Figure 3(b).

Step 5: Divide four coefficient sets: HL_{13}, LH_{13}, HL_{23} and LH_{23} into 4 x 4 blocks.

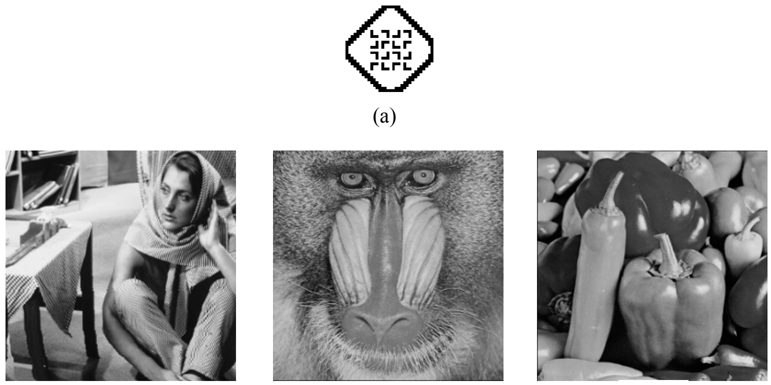
Step 6: Perform DCT on each block in the chosen coefficient sets (HL_{13}, LH_{13}, HL_{23} and LH_{23}).

Step 7: Regenerate the two pseudorandom sequences (PN_0 and PN_1) using the same key which used in the watermark embedding procedure.

Step 8: For each block in the coefficient sets: HL_{13}, LH_{13}, HL_{23} and LH_{23} calculate the correlation between the mid-band coefficients and the two generated pseudorandom sequences (PN_0 and PN_1). If the correlation with the PN_0 was higher than the correlation with PN_1, then the extracted watermark bit is considered 0, otherwise the extracted watermark is considered 1.

Step 9: The scrambled watermark is reconstructed using the extracted watermark bits.

Step 10: scramble the extracted watermark with Arnold algorithm with the same key times and gain the scrambled watermark W (i, j), and compute the similarity between the original and extracted watermarks.



(a)

(b) (c) (d)

Figure 5. (a) The original watermark; (b) the original Barbara image; (c) the original Baboon image; (d) the original pepper image.

5. Experimental results

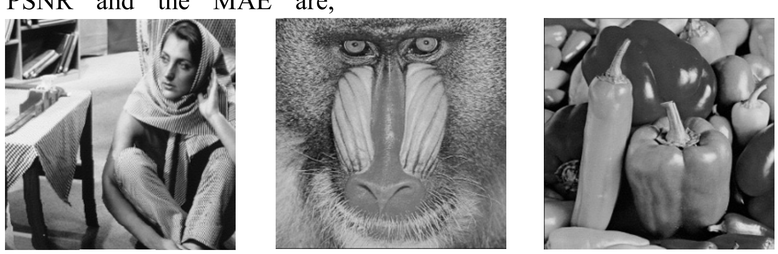
In this section the results of our study is shown. Several experiments are done to evaluate the effectiveness of the presented watermarking algorithm. In this experiment, a 32×32 binary image, as shown in Figure 5(a) is taken as the watermark of images. By using a row-major algorithm, the scrambled watermark image can be transformed into a binary sequence with a length of 1024. Additionally, Figure 5(b)–(d) display three 512×512 examined images, Barbara, Baboon, and Peppers, respectively. Note that I and J are set to 512. In the proposed method, the four selected 64×64 DWT sub-band is divided into 4×4 blocks giving a total of 1024 blocks. With this number of blocks we can embed 1024 bit in our image. The performance of the watermarking methods under consideration is investigated by measuring their imperceptible and robust capabilities. For the imperceptible capability, a quantitative index, Peek Signal-to-Noise Ratio (PSNR), is employed to evaluate the difference between an original image O and a watermarked image $\overline{O}$. For the robust capability, the Mean Absolute Error (MAE) measures the difference between an original watermark W and the corresponding extracted watermark $\hat{W}$. The PSNR and the MAE are, respectively, defined by equation 9 and 10; respectively,

$$\mathrm{PSNR}\left(\mathrm{O},\overline{\mathrm{O}}\right)=10\log_{10}\frac{255\times 255}{\frac{\sum_{i=0}^{I-1}\sum_{j=0}^{J-1}\left(\left\|o_{ij}-\overline{o}_{ij}\right\|\right)^{2}}{I\times J}} \quad (9)$$

and

$$MAE(W,\hat{W})=\frac{\sum_{i=0}^{|S|-1}\left\|w_i-\hat{w}_i\right\|_1}{|W|} \quad (10)$$

where $\|.\|_1$, $\|.\|_2$, and $|.|$ stand for the L1 norm, the L2 norm, and the number of components of a vector, respectively. A larger PSNR indicates that the watermarked image $\overline{O}$ more closely resembles the original image O, meaning that the watermarking method makes the watermark more imperceptible. Generally, if PSNR value is greater than 35dB the watermarked image is within acceptable degradation levels, i.e. the watermarked is almost invisible to human visual system. A lower MAE reveals that the extracted watermark $\hat{W}$ resembles the original



(a) (b) (c)

Figure 6. (a) The watermarked Barbara image; (b) the watermarked Baboon image; (c) the watermarked Peppers

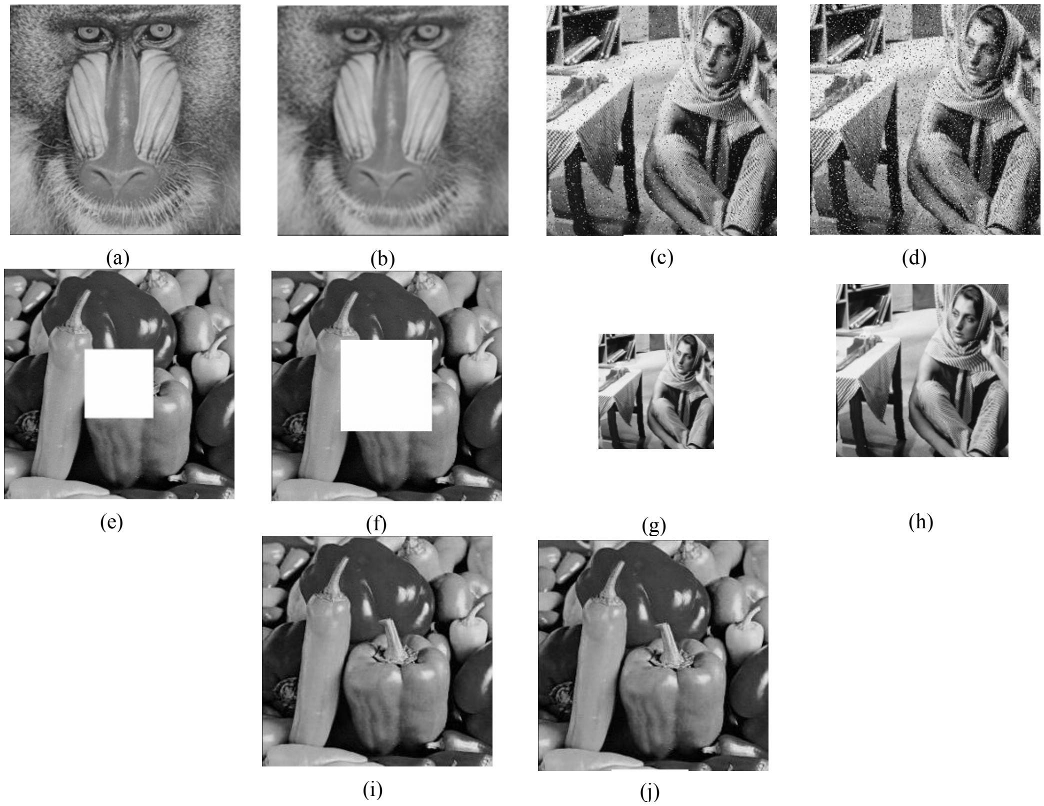


Figure 7. (a) and (b) show the watermarked Baboon image is manipulated by using a gaussian filtering with sigma =10 and filter size 3, 7 respectively; (c) and (d) display the watermarked Barbara image is corrupted by 5% and 10% Salt and pepper noises, respectively; (e) and (f) illustrate the watermarked Peppers image is cropped by 9% and 16%, respectively; (g) and (h) show the size of the watermarked Barbara image is scaled down by 50% and 75%, respectively; (i) and (j) displays the watermarked Peppers image is manipulated by using a jpeg compression with Image quality 5, 8, respectively.

watermark W more closely. The robustness of a watermarking method is assessed by comparing $\hat{W}$ with W, where $\hat{W}$ is extracted from the watermarked image $\overline{O}$ which is further degraded by attacks. If a method has a lower MAE (W, $\hat{W}$), it is more robust.

The watermarking performance of proposed method is compared with that of the method of Al-Haj [14]. To investigate the robustness of these methods, several attacks are simulated to degrade the watermarked images. Besides the quantitative results in terms of the PSNR and the MAE, the experiment also provides visual-comparison results. The presented method requires some parameters with the following values: watermark strength α = 25; key times N =12 in Arnold algorithm.

5.1. Attack-free case

An original image O and a scrambled watermark W are applied to the watermark-embedding procedure mentioned in Section 2.2. The corresponding watermarked image $\overline{O}$ is obtained following the completion of the watermark embedding procedure. The watermarked images are shown in Figure 6. The watermark extraction procedure described in Section 3.2 calculates the estimated watermark $\hat{W}$. The performance of the proposed method is compared with Al-Haj's method. Table.1 provides the quantitative results in terms of the PSNR and the MAE. Additionally, Figure 6 displays the visual comparison results for the extracted watermarks.

In this case Table 1 and Figures 6–8 show that the proposed method definitely makes the watermark W imperceptible.

Furthermore, the quality of each watermark, which is extracted by exploiting the proposed method, is superior to that of using the Al-Haj's method. In the following, several image-processing operations, including blurring, noising, cropping, scaling, and compression, are simulated to investigate the robustness of the three watermarking methods being considered. Let $\overline{O}$ denote the watermarked image O which is then manipulated by one of the above operations.

Table 1. The experimental results for the case of attack free

Image	PSNR	MAE	
		Al-Haj's	Proposed method
Barbara	37.88	0.03710937	0.02636718
Baboon	37.26	0.08886718	0.03222656
Peppers	37.45	0.03613281	0.01464843

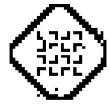
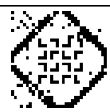
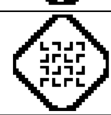
Image	Al-Haj's	Proposed Method
Barbara		
Baboon		
Peppers		

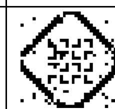
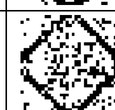
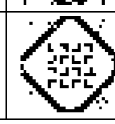
Figure 8. In attack-free case, the extracted watermarks by Al-Haj's, and the proposed methods for three watermarked images shown in Figure. 6.

5.2. Robustness to blurring

In order to simulate blurring attack, gaussian lowpass filter is used as a common blurring attack. It is implemented using Matlab function. The watermarked image $\overline{O}$ is further blurred. Three watermarks $\hat{W}$ are then extracted from the blurred and watermarked image $\overline{O}$ by using the three methods. Two cases are simulated here to degrade the three watermarked images. The first case involves a Gaussian lowpass filtering of the images with filter size 3 and $\sigma = 10$, while the second case involves coarser level of the blurring using gaussian lowpass filtering with filter size 7 and $\sigma = 10$. Figure 7(a) and (b) exhibit two blurred and coarser level of the gaussian lowpass filtering with filter size 3 and 7. Table 2 lists the quantitative results in terms of the MAE. Figure 9 shows the results for visual comparison. From observing Figure 9 and Table 2, it is evident that the proposed method outperforms the Al-Haj's method with regards to blurring attacks for these three images.

5.3. Robustness to noising

Figure 9. The extracted watermarks via using Al-Haj's and the proposed methods for three watermarked images further manipulated by the blurring attacks.

Attack	**Image**	**Al-Haj's**	**Proposed Method**
Gaussian lowpass filtering (hsize = 3, sigma=10)	Barbara		
	Baboon		
	Peppers		
Gaussian lowpass filtering (hsize = 7, sigma=10)	Barbara		
	Baboon		
	Peppers		

A noising scheme is performed by generating noises to corrupt the watermarked $\overline{O}$. The watermark $\hat{W}$ is extracted from the corrupted-and-watermarked image $\overline{O}$. The noising scheme generates 5% and 10% noise, respectively, to degrade the watermarked images.

Table 2. The experimental results in terms of the MAE for the case of blurring

Attack	Image	MAE	
		Al-Haj's	Proposed method
Gaussian lowpass filtering (hsize = 3, sigma=10)	Barbara	0.10449218	0.03906250
	Baboon	0.21484375	0.08984375
	Peppers	0.06152343	0.01464837
Gaussian lowpass filtering (hsize = 7, sigma=10)	Barbara	0.48046875	0.01269531
	Baboon	0.47949218	0.14062500
	Peppers	0.47753906	0.02050781

Table 3. The experimental results in terms of the MAE for the case of noising

Attack	Image	MAE	
		Al-Haj's	Proposed method
Salt & Pepper Noise addition (5%)	Barbara	0.09472656	0.03906250
	Baboon	0.1250000	0. 05859375
	Peppers	0.06152343	0.01464837
Salt & Pepper Noise addition (10%)	Barbara	0.18945312	0.06152343
	Baboon	0.18847656	0. 07519531
	Peppers	0.18261718	0. 02636718

Figure 7(c) and (d) exhibit two corrupted watermarked images for the corruption with 5% and 10% noise, respectively. Figure 10 and Table 3 show the quantitative results in terms of the MAE and the visual-perception results, respectively. It is evident from these results that the proposed method is explicitly more robust against adding noise attacks than the Al-Haj's method.

5.4. Robustness to cropping

Two cases are simulated to crop the three watermarked images. One case involves a 9% cropping of watermarked image; cropped a square with size of 154 ×154 is cropped from center of watermarked image. The other involves a 16% cropping of watermarked image; cropped a square with size of 205 × 205 is cropped from center of watermarked image. Two instances are presented in Figure 7(e) and (f), respectively. Figure 11 and Table 4 provide the quantitative results and the visual-watermarked images further manipulated by the noising attacks.

Table 4. The experimental results in terms of the MAE for the case of Cropping

Attack	Images	MAE	
		Al-Haj's	Proposed method
Cropping (9%)	Barbara	0.03710937	0.02636718
	Baboon	0.08886718	0.03222656
	Peppers	0.03613281	0.01464843
Cropping (16%)	Barbara	0.06445312	0.05175781
	Baboon	0.12011718	0.05371093
	Peppers	0.06549687	0.03710937

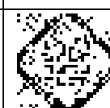
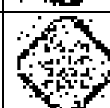
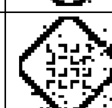
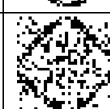
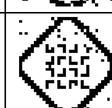
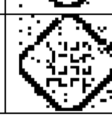
Attack	Image	Al-Haj's	Proposed Method
Salt & Pepper Noise addition (5%)	Baboon		
	Peppers		
	Barbara		
Salt & Pepper Noise addition (10%)	Baboon		
	Peppers		
	Barbara		

Figure 10. The extracted watermarks via using Al-Haj's and the proposed methods for three watermarked images further manipulated by the noising attacks.

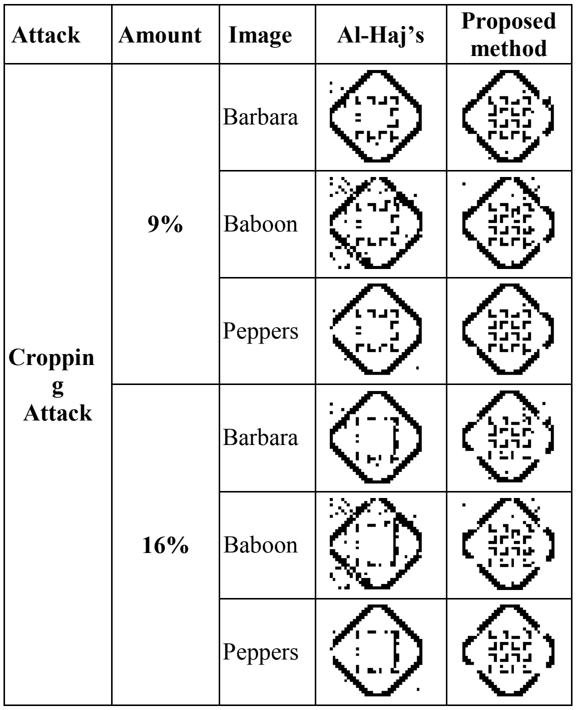


Figure 11. The extracted watermarks via using Al-Haj's and the proposed methods for three watermarked images further manipulated by the cropping attacks.

Figure 11 and Table 4, provide the quantitative results and the visual perception results for the case of cropping, respectively.

Table 5. The experimental results in terms of the MAE for the case of scaling

Attack	Test images	MAE	
		Al-Haj's	Proposed method
Scaling (50%)	Barbara	0.22363281	0.24050781
	Baboon	0.32812500	0.28417968
	Peppers	0.15039062	0.17089843
Scaling (75%)	Barbara	0.03441406	0.08691406
	Baboon	0.10156250	0.13835937
	Peppers	0.02638718	0.07031250

5.5. Robustness to scaling

Two scaling operations of 50% and 75% are utilized to deteriorate the watermarked image $\overline{O}$. Figure 7(g) and (h) display, respectively, two watermarked images which are distorted with these two scaling operations. For the scaling operation of 75%, the watermarked images with size 512 ×512 are shrunk to a size of 384 × 384.

For the scaling operation involving 50%, watermarked images with size 512 ×512 are shrunk to a size 256 × 256. Figure 12 and Table 5 show the quantitative results and the visual-perception results for the case of scaling, respectively. In case of scaling
to larger size, in both algorithms, watermark logo can extracted with very low MAE value.

5.6. Robustness to JPEG compression

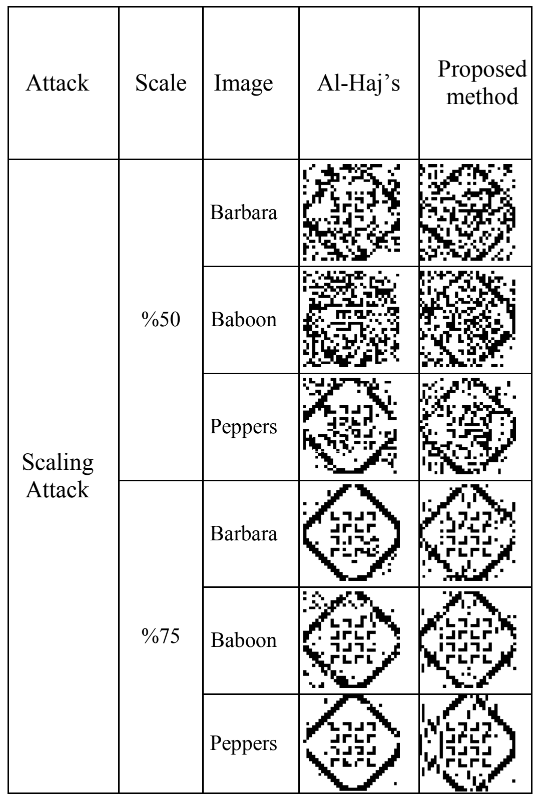


Figure 12. The extracted watermarks via using Al-Haj's and the proposed methods for three watermarked images further manipulated by the scaling attacks.

The watermark is embedded in the middle-frequency coefficients in both DWT and DCT. Thus proposed algorithm is robust against JPEG compression. Jpeg compression is implemented via Photoshop cs3 software in two case of medium and high image quality factor. Range of jpeg compression is changed between 1 to 12. 1 stand for coarsest level compression and 12 stand for softest level compression. Figure 13 and Table 6 provide the quantitative results and the visual-perception results for the case of JPEG compression, respectively. Two instances are presented in Figure 7(i) and (j), respectively. Table 6 shows that as the compression ratio decreased and the image quality factor increases, the similarity measurement between extracted watermark and original watermark increases accordingly. Also, it shows that in real compression proposed method is more robust than previous method.

Table 6. The experimental results in terms of the MAE for the case of JPEG compression watermarked images further manipulated by the jpeg compression attacks.

Attack	Test images	MAE	
		Al-Haj's	Proposed method
Image Quality factor (5)	Barbara	0.01074218	0.03417968
	Baboon	0.06933593	0.03125000
	Peppers	0.01367187	0.00488281
Image Quality factor (8)	Barbara	0.01074218	0.01854687
	Baboon	0.06933593	0.01660156
	Peppers	0.01269531	0.00000000

6. Conclusion

Our study focused on presenting a joint DWT-DCT digital image watermarking algorithm. Proposed method exploits strength of two common frequency domains method; DCT and DWT, to obtain further imperceptibility and robustness. The idea of inserting watermark in the combined transform is based on the fact that jointed transform could eliminate the drawback of each other. then, an effective watermarking method could obtains. In this paper, watermark is embedded in most robust and imperceptible parts of image than previous methods. Watermarking is done with embedding the watermark in the special middle frequency coefficient sets of 3-levels DWT transformed of a host image, followed by computing 4×4 block-based DCT on the selected DWT coefficient sets. In extraction procedure, pre-filtering operation, sharpening and Laplasian of Gaussian (LoG) filtering, is used to better detect watermark information from host image. Then, the same procedure as embedding algorithm is applied on pre-filtered attacked image to extract middle frequency coefficients of each DCT block. Afterwards, bits of watermark are extracted by comparing correlation between PN-sequences and these coefficients. Implementation results show that the imperceptibility of the watermarked image is acceptable. Presented method is tested by most of the common image processing attack such as: different size of gaussian filtering as an enhancement attack, adding salt and paper noise, scaling with two common factors: 50% and 75%, cropping, and compression attack. Specially, in case of adding noise and enhancement attack, proposed method show a significant improvement in robustness compare to previous DWT-DCT based method. Inasmuch as, the watermarks can be extracted from the other image processing attack with lower MAE values, proposed method is more robust compare to previous method, in spite of having the same imperceptibility and complexity.

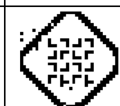
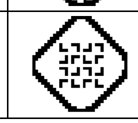
Attack	Rate	Image	Al-Haj's	Proposed Method
JPEG	Quality factor (5)	Barbara		
		Baboon		
		Peppers		
	Quality factor (8)	Barbara		
		Baboon		
		Peppers		

Figure 13. The extracted watermarks via using Al-Haj's and the proposed methods for three

7. References

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