A Combined DWT and DCT Watermarking Scheme Optimized Using Genetic Algorithm

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***Abstract*—To protect the copyright of digital image, this paper proposed a combined Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) based watermarking scheme. To embed the watermark, the cover image was decomposed by a 2-level DWT, and the HL2 sub-band coefficient was divided into 4x4 blocks, then the DCT was performed on each of these blocks. The watermark bit was embedded by predefined pattern_0 or pattern_1 on the middle band coefficients of DCT. After watermark insertion, inverse DCT was applied to each of the 4x4 blocks of HL2 sub-band coefficient, and inverse DWT was applied to obtain the watermarked image. For watermark extraction, the watermarked image, which may be attacked by various image attacks, was decomposed with 2-level DWT and DCT similarly as watermark embedding process, then correlation between middle band coefficients of block DCT and the predefined pattern (pattern_0 and pattern_1) was calculated to decide whether a bit 0 or a bit 1 was embedded. Genetic algorithm was used for embedding and extraction parameters optimization. Optimization is to maximize PSNR of the watermarked image and NCC of the extracted watermark. Experiment results show that the proposed scheme in this paper is robust against many image attacks, and improvement can be observed when compared to other existing schemes.**

***Index Terms*—watermark, DWT, DCT, genetic algorithm, image**

I. INTRODUCTION

The development of Internet and computer has changed our society. Digital multimedia can be copied and transmit easily and conveniently. Images, audio and video can be edited and modified illegally by some advanced processing software. The protection of copyright of digital multimedia becomes an important issue. Researchers are aware of this problem and some solutions have been proposed.

Digital watermarking techniques can provide detection and protection of copyrighted digital multimedia. Watermarking technique embeds specific information or copyright codes called watermark into the original media invisibly. In the case of dispute over the ownership of the media, embedded watermark can be extracted and it can be used to identify the ownership.

Digital watermarking algorithms can be classified into different types according to their embedding domain and characteristics.

Based on the resistance to attacks, it can be divided into robust watermarking [1-5], fragile watermarking [6-8] and semi-fragile watermarking algorithms [9-11]. Robust watermarking is designed to resist intentional and unintentional destroy to the watermark. Conversely, fragile watermark is designed to be easily destroyed by any kind of manipulations on the protected media. It is used for strict authentication. On the other hand, semi-fragile watermarking combines characteristics of fragile and robust watermarking techniques. In semi-fragile watermarking scheme, a watermark is embedded such that it can undergo some specific image processing operations while it is still possible to detect malevolent alterations to the media.

Based on embedding domain, digital watermarking algorithms can be classified into spatial domain [12, 13] and transform domain [14-21].Embedding watermarks in spatial domain are conceptually simple and have very low computational complexities, while algorithms based on the transform domain are more robust. Some of the transform domain methods available in the literature are listed as follow: methods based on discrete cosine transform (DCT) [14, 15], discrete wavelet transform (DWT) [16, 17], discrete Hadamard transform [18, 19], singular value decomposition [20] and discrete Fourier transform [21].

In [14], Zhang et al. proposed an improved watermarking algorithm based on DCT. First, both rows and ranks of the watermark were extended by using the proposed method before the embedding stage. After expansion, Sine chaotic system was employed in encrypting the watermark. In the embedding stage, an effective and adaptive embedding method was proposed to embed the watermark into the blocked DCT coefficients. Experimental results demonstrated that the proposed algorithm works well in resisting both geometry attack and noise attack. It also worked well in recovering

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the watermark after image suffered from JPEG compression.

In [22], Wang et al. proposed a wavelet-tree-based blind watermarking scheme for copyright protection. The wavelet coefficients of the host image were grouped into so-called super trees. The watermark was embedded by quantizing super trees. The trees were so quantized that they exhibit a large enough statistical difference, which will later be used for watermark extraction. Each watermark bit was embedded in perceptually important frequency bands, which renders the mark more resistant to frequency based attacks. Also, the watermark was spread throughout large spatial regions. This yields more robustness against time domain geometric attacks.

In this paper, we propose a robust watermarking scheme based on combined DWT and DCT. In the embedding scheme, firstly, the original image is decomposed using 2-level DWT, then a 4x4 block DCT decomposing is performed on the HL2 coefficients of DWT. After that, the watermark is embedded in the middle band coefficients of DCT. There are two predefined watermark pattern, according to the bit of the watermark image is 0 or 1, one of the watermark patterns is scaled by the gain factor and added to the middle band coefficients of DCT. Then the inverse DCT and DWT is applied to obtain the watermarked image. In the extraction scheme, the DWT and DCT transform are applied similarly as in the embedding scheme, then the correlation between the middle band coefficients of DCT and the two predefined watermark pattern is calculated to decide whether a bit 0 or bit 1 is embedded in the image. Moreover, we use genetic algorithm to find the optimal embedding parameters including the gain factor and frequency bands for watermark embedding into the DCT coefficients, which can improve robustness and image quality of the watermarked image.

The rest of the paper is organized as follows. The genetic algorithm principle is described in Section 2. The proposed method is presented in Section 3. Then, experimental results are presented in Section 4. Finally, we conclude this paper in Section 5.

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II. Genetic Algorithm Principles

Genetic algorithm (GA) is one of the most widely used artificial intelligent techniques for optimization. GA was first developed by John Holland [23]. GA is stochastic searching algorithm based on the mechanisms of natural selection and genetics, and is very efficient in searching for global optimum solutions.

GA process can be described based on three functional units. They are selection, crossover and mutation operations. The implementation of GA is briefly summarized as follows. Firstly, a set of number strings called population, which is composed of a group of chromosomes, are randomly generated to represent the solutions of the optimization problem. The elements in the strings, called “genes”, are adjusted to minimize or maximize the fitness value generated by the fitness function. The chromosome with good fitness value has greater chance to survive during the evolution process. The objective function is problem specific; it should be carefully defined by the designers. Then, the selection operator performs a selection function on the chromosomes. The chromosomes are copied from one set to the next according to their fitness values. Next, the crossover operator chooses pairs of chromosomes at random and produces two new offspring. A crossover point is selected between the two parents’ chromosomes. Two new offspring are produced by exchange the fractions of two parents’ chromosome after the crossover point. After that, the mutation operator randomly changes the value of bits in a chromosome. It can keep GA from converging too fast. The mutation rate should be low. Similarly, the fitness value of the offspring is calculated as their parents in order to replace the chromosomes in the current generation. The GA cycle is repeated until maximum number of generations is reached or the objective value is below a threshold. With the fundamental concepts in GA, we are able to design an optimized DWT and DCT based watermarking scheme with the aid of GA.

The genetic algorithm toolbox developed by the University of Sheffield is one of the most popular used genetic algorithm toolbox, and it is used in this paper.

III. Proposed Method

In the proposed method, both DWT and DCT are performed on the image. For DCT, there are three frequency sub-bands: low band frequency, middle band frequency and high band frequency. The low band frequency contains most of the signal energy and most important visual parts of the image. If watermark embeds in low band frequency, the imperceptibility will be poor although it will be robust to many image attacks. Also, the watermark cannot be embedded into high band frequency, because high band frequency may be removed by JPEG compression and noise attacks. Therefore, the watermark should be better embedded into the middle band frequency to trade-off between robustness and imperceptibility [24-27].

DWT decompose an image into four non-overlapping multi-resolution sub-bands LL1, HL1, LH1 and HH1. LL1 is the approximation coefficients, HL1, LH1 and HH1 are details coefficients (horizontal, vertical, and diagonal, respectively). To obtain 2-level DWT coefficients, the sub-band LL1 is further decomposed. And as mentioned in [28], HL2 is selected to embed watermark in this paper.

A. Watermark Embedding

The watermark embedding procedure is represented in Figure 1, followed by a detailed explanation.

Step 1: Perform DWT on the cover image to decompose it into four non-overlapping sub-bands: LL1, HL1, LH1, and HH1.

Step 2: Perform DWT again on the HL1 sub-band to get four smaller sub-bands: LL2, HL2, LH2, and HH2 as show in Figure 2.

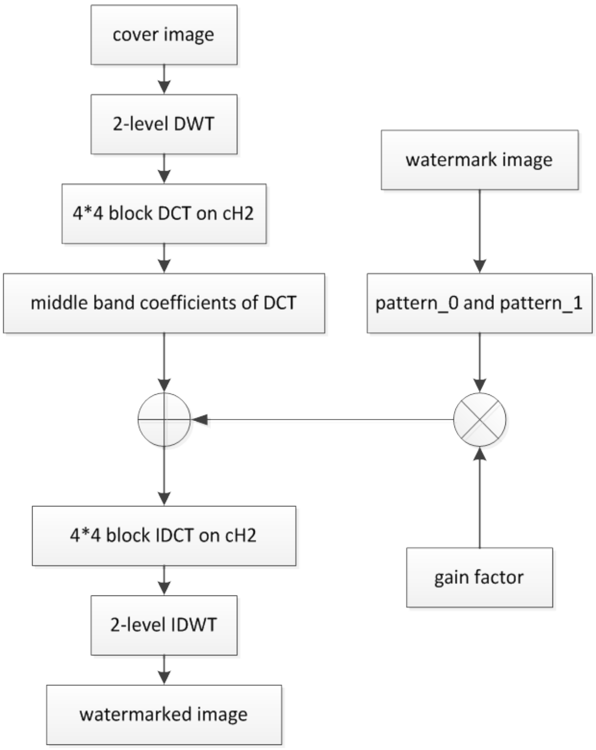


Figure 1 Embedding scheme

Step 3: Divide the sub-band HL2 into 4x4 blocks.
Step 4: Perform DCT to each block in the HL2 sub-band.
Step 5: Generate a pseudorandom sequence or called "pattern_0" by a key, and inverse each bit of pattern_0 to get pattern_1. The length of pattern_0 and pattern_1 is equal to the number of selected middle band coefficients of DCT. Where pattern_0 is used to embed the watermark bit 0 and pattern_1 is used to embed the watermark bit 1.

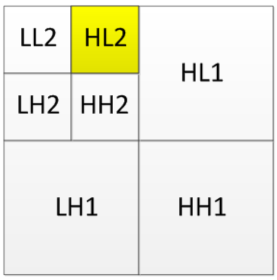


Figure 2 2-level DWT sub-bands

Step 6: Embed pattern_0 and pattern_1 with a gain factor in the middle band coefficients of DCT as follow:

$$X' = \begin{cases} X + \alpha * pattern\_0 & if\ watermark\ bit = 0 \\ X + \alpha * pattern\_1 & if\ watermark\ bit = 1 \end{cases} \quad (1)$$

Where, α is the gain factor, X is the selected middle band coefficients of DCT before embedding, and X' is middle band coefficients of DCT after embedding.

Step 7: Perform the inverse DCT on each 4x4 block after pattern_0 and pattern_1 are added to the selected middle band coefficients.
Step 8: Perform the inverse DWT on the image to produce the watermarked image.

B. Watermark Extraction

The watermark extraction scheme is show in Figure 3, and the details are described as follows.

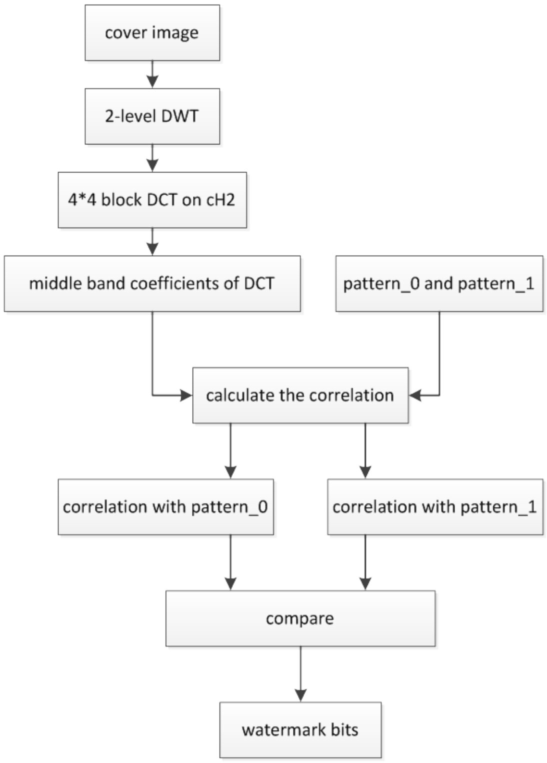


Figure 3 Extraction scheme

Step 1: Perform DWT on the cover image to decompose it into four non-overlapping sub-bands: LL1, HL1, LH1, and HH1.
Step 2: Perform DWT again on the HL1 sub-band to get four smaller sub-bands: LL2, HL2, LH2, and HH2 as show in Figure 2.
Step 3: Divide the sub-band HL2 into 4x4 blocks.
Step 4: Perform DCT to each block in the HL2 sub-band.
Step 5: Regenerate the two pseudorandom sequences using the same key which used in the watermark embedding scheme.
Step 6: For each block in the sub band HL2 calculate the correlation between the middle band coefficients and the two generated pseudorandom sequences. If the correlation with pattern_0 is higher than the correlation with pattern_1, then the extracted watermark bit is considered to be 0, otherwise the extracted watermark is considered to be 1.
Step 7: The watermark image is reconstructed according to the watermark bits.

C. Performance Improvement using GA

Watermarking problem can be viewed as an optimization problem. There are three conflicting requirements: robustness, imperceptibility and capacity. NCC indicates the amount of similarity between the original watermark image and the extracted watermark image. It reflects the robustness of a watermark scheme. Imperceptibility of a watermark scheme can be described by PSNR. PSNR is inversely proportional to the amount of distortion introduced to the host image. Capacity describes the amount of bits can be embedded into the cover image. So, in a good watermarking scheme, all the three elements, PSNR, NCC and capacity should be as large as possible. At the other hand, the three elements are related with each other. Maximization of PSNR decreases the value of other two elements, and so does NCC and capacity. So, GA is used to find the optimum value of parameters used in the watermarking scheme to obtain the trade-off between the three conflicting elements. However, capacity is often application specific. In this paper, capacity is 1024 bits, PSNR is targeted to 40 dB and NCC is targeted to 1.0. So the fitness function abs ((40-PSNR) + (1-NCC)) is defined for the GA optimize procedure.

PSNR can be defined as follows:

$$\mathrm{PSNR} = 10 * log_{10} * \frac{255*255}{1/(M*N)\sum_{x=1}^{M}\sum_{y=1}^{N}[f(i,j)-g(i,j)]^2} dB \quad (2)$$

There, M and N are the height and width of the image, respectively. $f(i,j)$ and $g(i,j)$ are the pixel value of cover image and the attacked image, respectively. The NCC is computed after the watermark is extracted from the attacked image. NCC can be defined as follow:

$$\mathrm{NCC} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}[w(i,j)-w_{mean}][v(i,j)-v_{mean}]}{\sqrt{(\sum_{i=1}^{m}\sum_{j=1}^{n}[w(i,j)-w_{mean}]^2)(\sum_{i=1}^{m}\sum_{j=1}^{n}[v(i,j)-v_{mean}]^2)}} \quad (3)$$

There, m and n are the height and width of the watermark, respectively. $w(i,j)$ and $v(i,j)$ are the pixel value of the original watermark and the extracted watermark respectively.

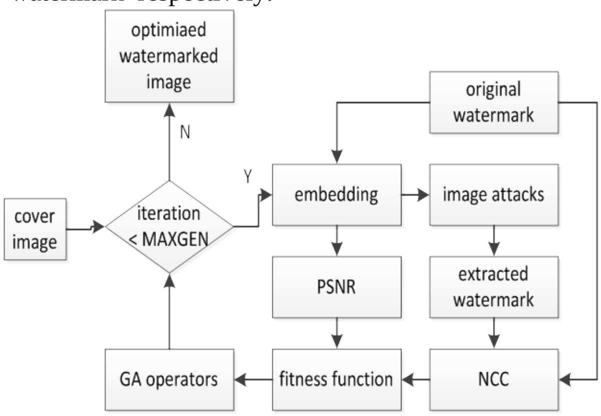


Figure 4 GA-based watermark embedding and extraction

Figure 4 shows the flow chart for GA-based watermark embedding and extraction. If the number of iteration is less than the defined maximal generation of GA, embed the original watermark into the cover image. After embedding, PSNR of the watermarked image is calculated, and the watermarked image may go through one or more image attacks, such as JPEG compression, Gaussian filter, cropping, rotation and so on. Then, extracted the watermark from the attacked image. Next, NCC between the original watermark and the extracted watermark is calculated. With PSNR and NCC, fitness value is obtained by the fitness function, and then GA operators (include selection, crossover, and mutation) yield the next generation parameters. This loop goes until the iteration of GA is equal to the defined maximum generation.

IV. Experimental Results

Lena image of size 512x512 is used as cover image and is shown in Figure 5. The watermark image of size 32x32 is shown in Figure 6. The watermarked image is shown in Figure 7. GA is used to find the optimum values of embedding gain factor and which four middle band coefficients of DCT to embed. To test the performance of the proposed watermarking scheme, MATLAB 7.12 and the genetic algorithm toolbox developed by the University of Sheffield is used. The GA parameters used in this paper are listed as follow: population size is 20; crossover rate is 0.8, mutation rate is 0.0056. Various attacks used to test the robustness of the watermarking scheme proposed in this paper are JPEG compression (with different quality factors), median filter, Gaussian filter, average filter, image sharpening, 50% and 200% scaling, 20%, 25% and 40% cropping, Gaussian noise, salt & pepper noise, row & column copying, row & column blanking, and rotation with different degrees. Moreover, the search space for GA optimize are: 12 to 50 for embedding gain factor and 1 to 15 for the DCT coefficients to embed.

With GA, gain factor used in the embedding scheme are 21 and the four DCT middle band coefficients are 3, 4, 5 and 8. Table 1 shows extracted watermark from attacked image and NCC values. PSNR value of the watermarked image without attack is 41.5213dB. Table 2 shows the performance comparison with existing schemes [22, 29, 30]. The proposed scheme in this paper is better than most of the schemes shown in the table.


Figure 5 Cover image

Figure 6 Watermark


Figure 7 Watermarked image, PSNR = 41.5213 dB

TABLE I. EXTRACTED WATERMARK FROM ATTACKED IMAGE AND NCC VALUES

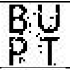
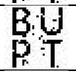
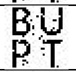
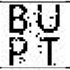
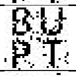
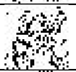
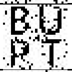
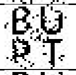
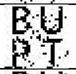
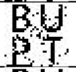
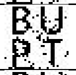
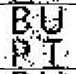
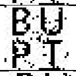
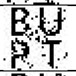
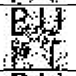
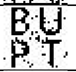
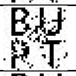
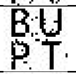
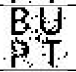
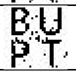
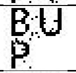
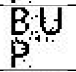
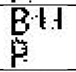
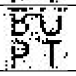
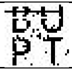
Attacks		Extracted watermark	NCC
JPEG	QF=90		0.9783
	QF=70		0.9721
	QF=50		0.9342
	QF=30		0.8943
	QF=20		0.8095
	QF=10		0.3675
rotation	10°		0.7817
	30°		0.7580
	0.25°		0.8235
	0.75°		0.7995
	1°		0.8390
	-0.25°		0.8242
	-0.75°		0.7986
	-1°		0.8394
Median filter	3x3		0.9032
	4x4		0.6387
Gaussian filter (3x3)			0.9117
Average filter (3x3)			0.8432
Image sharpening			0.9520
Scaling	50%		0.8667
	200%		0.9245
Cropping	25%		0.9364
	20%		0.9311
	40%		0.8731
Gaussian noise (0.001)			0.8895
Salt & pepper noise(0.001			0.8990
Row & Column copying (10-30, 40-70, 100-120)			0.7962
Row & column Blanking (30, 70, 120)			0.7920

TABLE II. COMPARISON OF THE PROPOSED METHOD WITH THE METHODS OF LIEN ET AL. [22], LI ET AL. [29]AND WANG ET AL. [30]

Type of attacks	Wang et al. [30] (PSNR=38.2 dB)	Li et al. [29] (PSNR = 40.6 dB)	Lien et al. [22] (PSNR = 41.54 dB)	This paper (PSNR = 41.52 dB)
Median filter(3x3)	0.51	0.35	0.79	0.90
Median filter(4x4)	0.23	0.26	0.51	0.64
JPEG, QF= 10	NA	0.15	0.17	0.37
JPEG, QF = 20	NA	0.34	0.61	0.81
JPEG, QF= 30	0.15	0.52	0.79	0.89
JPEG, QF= 50	0.28	0.52	0.89	0.93
JPEG, QF = 70	0.57	0.63	0.97	0.97
JPEG, QF = 90	1	0.78	1	0.98
Image Sharpening	0.46	0.38	0.88	0.95
Gaussian filter	0.64	0.70	0.84	0.91
Rotation 0.25°	0.37	0.46	0.53	0.82
Rotation 0.75°	0.26	0.36	0.16	0.80
Rotation 1°	0.24	0.33	0.07	0.84
Rotation - 0.25°	0.32	0.50	0.47	0.82
Rotation - 0.75°	0.24	0.29	0.10	0.80
Rotation - 1°	0.16	0.33	0.16	0.84
Cropping 25%	NA	0.61	0.92	0.94
Scaling 50%	NA	0.35	0.79	0.87

V. CONCLUSION

In this paper, a robust watermarking scheme based on DWT and DCT is presented, and is optimized with GA. HL2 sub-band of DWT coefficient is decomposed with 4x4 block DCT. In each block, the four middle band coefficients are used to embed the watermark. To embed a bit 0, the predefined pattern_0 is scaled by a gain factor and added to the middle band coefficient of the block DCT. To embed a bit 1, the predefined pattern_1 is done similarly as pattern_0 when embed a bit 0. To extract the watermark, correlation between the predefined pattern (pattern_0 and pattern_1) and the middle band coefficients of block DCT is calculated. If the correlation between pattern_0 and the middle band coefficients of block DCT is larger, then the extracted watermark bit is consider to be 0, otherwise, the extracted watermark bit is consider to be 1. GA is used to find the optimum value of gain factor and to find which four middle bands of coefficient of block DCT are used to embed the watermark. The PSNR and NCC of the proposed scheme are tested with Lena image and a binary watermark image of size 32x32. Compared with other methods [22, 29, 30], the proposed scheme is better than most of the schemes.

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