SVD Based Robust Digital Watermarking For Still Images Using Wavelet Transform

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ABSTRACT

This paper aims at developing a hybrid image watermarking algorithm which satisfies both imperceptibility and robustness requirements. In order to achieve our objectives we have used singular values of Wavelet Transformation's HL and LH sub bands to embed watermark. Further to increase and control the strength of the watermark, we use a scale factor. An optimal watermark embedding method is developed to achieve minimum watermarking distortion. A secret embedding key is designed to securely embed the fragile watermarks so that the new method is robust to counterfeiting, even when the malicious attackers are fully aware of the watermark embedding algorithm. Experimental results are provided in terms of Peak signal to noise ratio (PSNR), Normalized cross correlation (NCC) and gain factor to demonstrate the effectiveness of the proposed algorithm. Image operations such as JPEG compression from malicious image attacks and, thus, can be used for semi-fragile watermarking.

KEYWORDS

Watermarking, Wavelet transform, multiscale embedding, Wavelet subspaces.

1. INTRODUCTION

Digital media offers several distinct advantages over analog media, such as high quality, easy editing, high performance and easy duplication. The high spreading of broadband networks and new developments in digital technology has made ownership protection and authentication of digital multimedia a very important issue. Digital watermarking provides a possible solution to the problem of easy editing and duplication of images, since it makes possible to identify the author of an image by embedding secret information in it.

Watermarking systems are robust or fragile. Robust watermarks are designed to resist any modifications and are designed for the copyright protection. Fragile watermarks are designed to fail whenever the cover work is modified and to give some measure of the tampering. Fragile

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watermarks are used in authentication. The fragile watermarks can be embedded in either the space domain or the transformed domain of an image. In the space domain, several fragile watermarking methods that utilize the least significant bit (LSB) of image data. A digital signature of the most significant bits of an image block is replaced by the least significant bits of the same block on a secret user key.

Watermarking techniques can be broadly classified into two categories spatial domain methods and Frequency (transform) domain methods [3] and [4]. Spatial domain methods are based on direct modification of the values of the image pixels, so the watermark has to be imbedded in this way. Such methods are simple and computationally efficient, because they modify the color, luminance or brightness values of a digital image pixels, therefore their application is done very easily, and requires minimal computational power.

Frequency (transform) domain methods are based on the using of some invertible transformations like discrete cosine transform (DCT), discrete Fourier transform (DFT), discrete wavelet transform (DWT) etc. to the host image. Embedding of a watermark is made by modifications of the transform coefficients, accordingly to the watermark or its spectrum. Finally, the inverse transform is applied to obtain the marked image. This approach distributes irregularly the watermark over the image pixels after the inverse transform, thus making detection or manipulation of the watermark more difficult. The watermark signal is usually applied to the middle frequencies of the image, keeping visually the most important parts of the image (low frequencies) and avoiding the parts (presented by high frequencies), which are easily destructible by compression or scaling operations. These methods are more complicated and require more computational power. The rest approaches are based on various modifications of both methods above, using useful details of them to increase the quality of whole watermarking process.

It is well known that there are three main mutually conflicting properties of information hiding schemes: *capacity, robustness and indefectibility* [4]. It can be expected that there is no a single watermarking method or algorithm with the best quality in the sense that three mentioned above properties have the maximum value at once. But at the same time it is obvious that one can reach quite acceptable quality by means of combining various watermarking algorithms and by means of manipulations in the best way operations both in the spatial and in the frequency domains of an image. In paper [5] an approach to combining of DWT and DCT to improve the performance of the watermarking algorithms, which are based solely on the DWT, is proposed. Watermarking was done by embedding the watermark in the first and second level DWT sub-bands of the host image, followed by the application of DCT on the selected DWT sub bands. The combination of these two transforms improved the watermarking performance considerably when compared to the DWT-only watermarking approach. As a result this approach is at the same time resistant against copy attack. In addition, the fragile information is inserted in a way which preserves robustness and reliability of the robust part.

The paper is organized as follows. An introduction about the paper is given in Section I. The proposed approach is presented in Section II. Experimental results are demonstrated in Section III. Conclusions and scope for future work are drawn in Section IV.

1.2. DIGITAL IMAGE WATERMARKING IN THE WAVELET DOMAIN

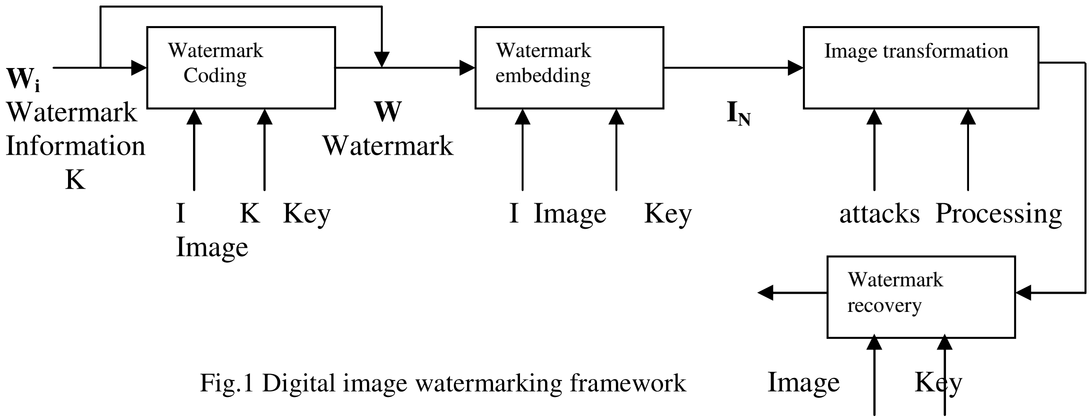
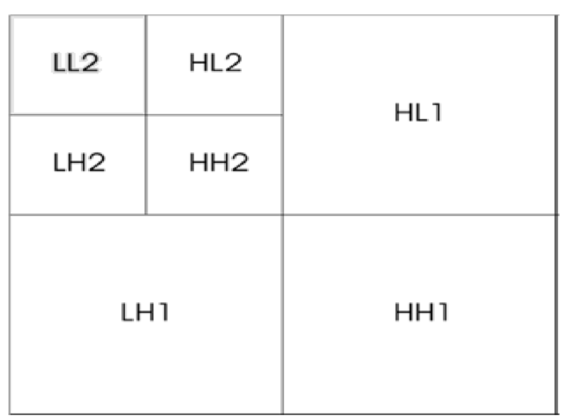


Fig.1 Digital image watermarking framework

The DWT can be implemented as a multistage transformation. An image is decomposed into four subbands denoted LL, LH, HL, and HH at level 1 in the DWT domain, where LH, HL, and HH represent the finest scale wavelet coefficients and LL stands for the coarse-level coefficients. The LL subband can further be decomposed to obtain another level of decomposition. The decomposition process continues on the LL subband until the desired number of levels determined by the application is reached. Since human eyes are much more sensitive to the low-frequency part (the LL subband), the watermark can be embedded in the other three subbands to maintain better image quality. The basic idea behind the SVD-based watermarking techniques is to find the SVD of the cover image or each block of the cover image, and then modify the singular values to embed the watermark.



L - Low Frequency Sub bands

H- High Frequency Sub bands

1,2 – Decomposition Levels

Fig.2. Wavelet transformation on images

Lahouari Ghouti , Ahmed Bouridane, Mohammad K. Ibrahim and Said Boussakta [2] have proposed a new perceptual model, which is only dependent on the image activity and is not dependent on the multifilter sets used. To achieve higher watermark robustness, the watermark embedding scheme is based on the principles of spread-spectrum communications.

Satisfying both imperceptibility and robustness for an image watermarking technique always remains a challenge because both are conflicting requirements. Since performing SVD on an image is computationally expensive, a hybrid DWT-SVD-based watermarking scheme is developed that requires less computation effort yielding better performance. Rather than embedding watermark directly into the wavelet coefficients, Chih-Chin Lai and Cheng-Chih Tsai have proposed to embed watermark in to the elements of singular values of the image's DWT sub bands. [4]

In order achieve both image authentication and protection simultaneously, Chun-Shien Lu , and Hong-Yuan Mark Liao [5] proposes a cocktail watermarking which can resist different kinds of attacks and embed 2 watermarks (fragile & Robust). Existing systems have used invariant properties of DCT coefficients and relationships between the coefficients for watermark embedding but they modify a large amount of data and produces maximum distortion. So a new method that uses Gaussian mixture model, Expectation Maximization algorithm, secret embedding key and private key for watermark embedding is proposed by Hua Yuan and Xiao-Ping Zhang [6].

Though there are existing systems that provides perceptual invisibility and robustness**,** YiweiWang, John F. Doherty & Robert E. Van Dyck [8] have proposed a new wavelet based technique for ownership verification by giving importance to the private control over the watermark and using randomly generated orthonormal filter banks. Liehua Xie and Gonzalo R. Arce [9] have proposed a concept of using compression algorithms which are based on wavelet decompositions. In this approach, the SPIHT compression algorithm is executed to obtain a hierarchical list of the significant coefficients and at least 3 coefficients that correspond to the ones with the largest absolute is selected. The watermark is embedded into the host image based on the selected coefficients.

Mauro Barni, Franco Bartolini and Alessandro Piva [10] have proposed a new algorithm different from other existing systems in wavelet domain where the masking is performed pixel by pixel by taking into account the texture and the luminance content of all the image sub bands.A blind watermarking scheme that is robust against JPEG compression, Gaussian noise, salt and pepper noise, median filtering, and ConvFilter attacks was proposed by Ning Bi, Qiyu Sun, Daren Huang, Zhihua Yang, and Jiwu Huang [11]. This new approach uses Multiband wavelet transform and they embed the watermark bits in the mean trend of some middle-frequency sub images in the wavelet domain.

T. M. Ng and H. K. Garg [12] use a Laplacian model in place of Gaussian distribution along with the ML detection for better performance. Existing systems make use of wavelet coefficients and embed watermark bits directly into the coefficients whereas the system proposed by Shih-Hao Wang and Yuan-Pei Lin [13] groups the wavelet coefficients into super tress and embed watermarks by quantizing super trees.

Generally different resolutions of an image can be obtained using wavelet decomposition. Since human eyes are insensitive to the image singularities revealed by high frequency sub-bands, adding watermark to these singularities increases the quality of the image by providing imperceptibility. But the existing wavelets have limited ability to reveal singularities in all directions. So Xinge You, Liang Du & Liang Du [15] construct the new nontensor product wavelet filter banks, which can capture the singularities in all directions.A novel multipurpose digital image watermarking method [16] has been proposed based on the multistage vector quantizer structure, which can be applied to image authentication and copyright protection applications.

Let X be the original gray-level image of size N1 X N2, and the digital watermark be a binary image of size M1 X M2 as shown in Fig 2 and Fig 3. The middle-frequency range of the host image will be processed during the watermark embedding. For more robust and invisible embedding, the amount of information to be embedded should be reduced [7].

The original image X and digital watermark W are represented as

$$X = \{ x(i, j), 0 < i < N1, 0 < j < N2 \}$$

$$W = \{ w(i, j), 0 < i < M1, 0 < j < M2 \}$$

1.2.1 WATERMARK EMBEDDING

Step 1. For a given $N \times N$ image, apply the discrete wavelet Transform up to 3rd level, which produce a total of 9 bands wavelet coefficients.

Step 2. The middle frequency sub-bands HL and LH from 2nd level of wavelet decomposition are used to get 3rd level decomposition.

Step 3 . The watermark of size M×M is converted into binary pattern.

Step 4. The binary image is scaled to the size of original host image and then duplicated.

Step 5. Pseudo random sequence is generated using a secret key and combined with the duplicated watermark to increase robustness.

Fig 3 .Watermark Image

Fig 4 .Host Image

Step 6. The resultant watermark is then embedded into the middle frequency sub-bands of host image.

Step 7. Finally, inverse DWT is performed to produce the watermarked image.

2.2 WATERMARK EXTRACTION

Step 1. For a given $N \times N$ watermarked image, apply the discrete wavelet Transform up to 3rd level, which produce a total of 9 bands of wavelet coefficients.

Step 2. The middle frequency sub-bands HL and LH from 2nd level of wavelet decomposition are used to get 3rd level decomposition.

Step 3. Same secret key used in the embedding process enables to generate the random sequence.

Step 4. Finally, the watermark is extracted from the selected wavelet coefficients.

Step 5. After extracting the final watermark, compares it with the original watermark, to find the any attacks happened in the original data.

2. PROPOSED WORK

2.1 WATERMARK EMBEDDING

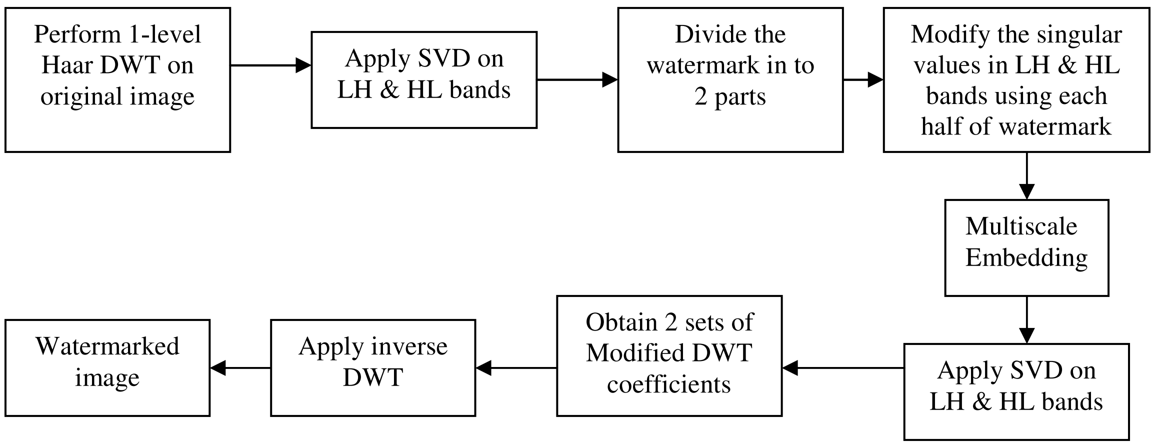


Fig.5. Block Diagram for Watermark Embedding Algorithm

A 1-level Haar DWT is performed on the original image to decompose it into four sub bands (i.e., LL, LH, HL, and HH). Then select LH and HL sub bands and perform Singular value decomposition (SVD) on them. Next the watermark is divided into 2 parts. The singular values in HL and LH sub bands are modified using the half of the watermark image and then SVD is applied to them [5]. Also, a scale factor is used along with it to control the strength of the watermark to be inserted. As a result we obtain two sets of modified DWT coefficients (LH & HL sub-bands) and two sets of non modified DWT coefficients (LL & HH sub-bands). Inverse DWT is applied on them to obtain the watermarked image. This is illustrated in fig 4.

A novel multiscale fragile watermarking method that embeds watermarks at multiscale wavelet subspaces is presented, based on statistical modeling of the image in the wavelet domain. The EM algorithm consists of two steps. The E step calculates the individual state probabilities for each wavelet coefficient $P_{s,i},P_{l,i.}$ and the M step involves simple closed-form updates for the variances $[\sigma_s^2,\sigma_i^2]$ and the overall state probabilities $[P_{s,}\ P_l]$. An overview of the watermark embedding process authentication messages are first translated into binary bit streams [8]. Then the wavelet subspaces at multiple scales are divided into a number of wavelet watermarking blocks depending on the number of message bits being embedded and the number of wavelet scales these bits will spread into. The binary bit streams are then embedded into the wavelet watermarking blocks by forming some special relationships defined by the code map. The whole watermarking embedding process is secure and robust to malicious attacks because it is performed on a private key basis that guides a secret mapping between embedded bits and their corresponding wavelet watermarking blocks.

To make the large variance parameter σ_i^2 the same value as $\sigma_i'^2$, each large coefficient s_i will be modified by a certain amount Δs_i, such that

$$\frac{1}{K}\sum_{i=1}^{P}\left[\left(E_i+\Delta E_i\right)^2-E_i^2\right]=\sigma_l^{j2}-\sigma_l^2 \quad - (1)$$

Where ***P*** is the number of coefficients that are modified and ***K*** is the total number of coefficients in the wavelet subspace. It is straightforward to see that once (1) is satisfied, the variance differences contributed by each coefficient modification will compensate the overall variance parameter difference.

Suppose σ_i^2 and $\sigma_i'^2$ are the large variance parameters of two sets of the wavelet coefficients, denoted by S and S'. Let s_i,*i=1,..P*, represent the *P* coefficients to be modified in the set S with σ_i^2 , and the total number of coefficients in that wavelet subspace is K. If each coefficient s_i, *i=1,..P*, is modified by a respective amount Δs_i, in order to make σ_i^2 and $\sigma_i'^2$ equal, then the optimal way of modification with least image mean square distortion is that all coefficient s_i are modified with a constant proportional rate α , that is, $\Delta s_i = \alpha s_i$, *i=1,..P*, where the constant α is determined by the following equation:

$$\sum_{i=1}^{P}\left[E_i(1+\alpha)^2 - E_i^2\right] = K(\sigma_l'^2 - \sigma_l^2) \quad - (2)$$

It is noted that the two large variance parameters σ_i^2 and $\sigma_i'^2$ should be obtained through the EM algorithm. Therefore, an iterative approach involving the modification and the EM algorithm in each single step is required to finally adjust the large variance parameter σ_i^2 to the target value $\sigma_i'^2$ as shown in the fig .5.

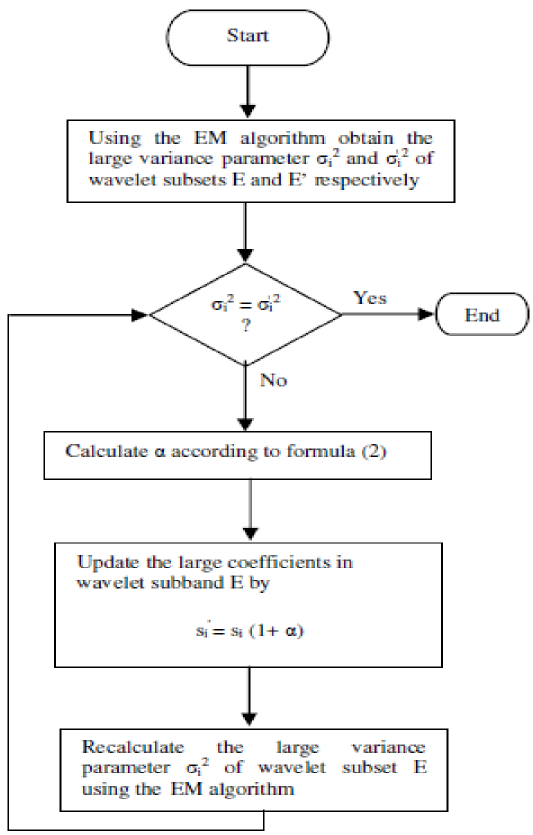


Fig 6. Flowchart for calculating coefficient

2.2 WATERMARK EXTRACTION

A 1-level Haar DWT is performed on the watermarked (possibly distorted) image. The image is decomposed it into four sub bands: LL, LH, HL, and HH. Select LH and HL sub bands and perform Singular value decomposition (SVD) on them. Orthogonal matrices of host image are combined with the singular value (diagonal vector) of watermarked image and scale factor is removed from it. Each half of the watermark is extracted from the respective sub-bands .Both half of the watermarks are combined to obtain the embedded watermark. The extraction process is shown in Fig.6.

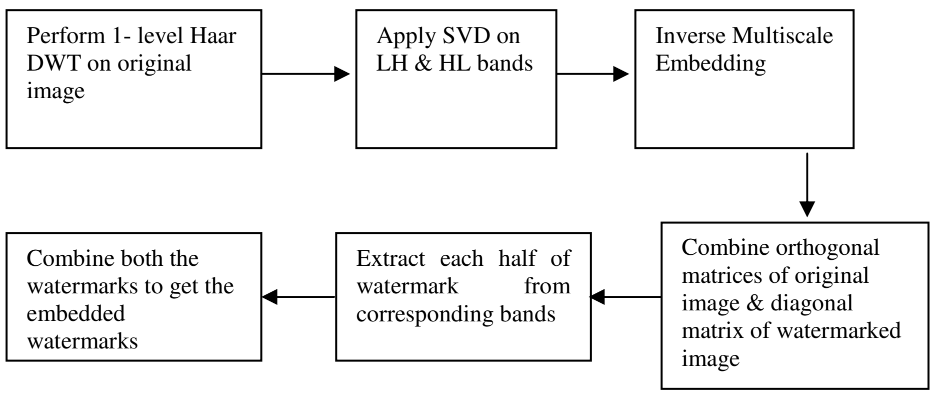


Fig.7. Block Diagram for Watermark Extraction Algorithm

3. EXPERIMENTAL RESULTS

A. Performance criteria

In the evaluation of the performance of the watermarking scheme, we use the normalized mean square error MSE between the original and watermarked images, respectively, and peak signal to noise ratio PSNR. The image pixels are assumed to be 8 bits to give a maximum pixel value of 255.

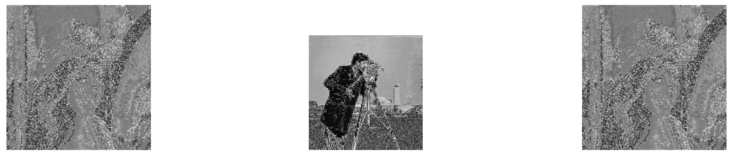
B. Experimental results

The DWT based watermark technique has been applied to several images, including the 256X256 sizes of Cameraman, Lena, Mandrill, and Peppers. In these experiments, we have chosen a random sequence for creating the watermark matrices. The embedded watermarks cause imperceptible distortion at levels that provide reliable detection.

PSNR (Peak signal to noise ratio) is used to measure the invisibility of the embedded watermark in carrier image. The experimental value is 55.88db.

NC (normalized cross-correlation) is used to measure the similarity between the extracted watermark and the original watermark. The value is 0.9966.

In order to test the performance of the proposed watermark algorithm, we used a set of experiments to verify the results of three attacks. From Table1, note that the proposed method can effectively resist attacks such as Gaussian, salt & pepper and Poisson noises.



Original Image Watermark Watermarked Image

Fig.8. Original, Watermark and Watermarked image of the Proposed Approach

Table1. PSNR values with different noise densities

NOISE	**NOISE DENSITY**	**MSE**	**PSNR-db**
Gaussian Noise	0.001 0.005	0.0034 0.0039	28.7120 28.5280
Salt & Pepper	0.001 0.005	1.5259e-005 1.5259e-005	53.1980 48.6342
Poisson	**---**	0.0030	31.9924

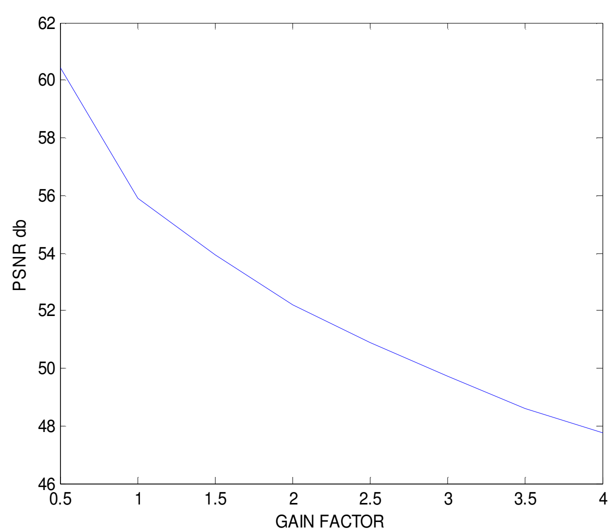


Fig.9. Gain factor vs PSNR

We observe that the watermarking strength S(I) decreases when the parameter Gain factor ρ increases, see Table 2 for the experimental results. So in the simulation, the watermarking strength parameter S(I) and ρ(I) and for an image is chosen as follows:

$$\rho(I) = 0$$
$$S(I) = S(\rho(I),I)$$

Table 2. PSNR and NCC for different gain factors

GAIN FACTOR	**PSNR-db**	**NCC**
0.5	60.4523	0.3565
1	55.889	0.9969
1.5	53.9383	0.7617
2	52.1956	0.6192
2.5	50.8678	0.5503
3	49.7159	0.5108
3.5	48.6042	0.4855
4	47.7310	0.4678

In most of our simulation, the PSNR value is greater than 45 dB as shown in Table 2. This shows that the algorithm has enough visual imperceptibility and high robustness against various attacks.

$$S(I)=\max\{S:PSNR(I,)>=45\}$$

4. CONCLUSION AND FUTURE WORK

The DWT technique provides better imperceptibility and higher robustness against attacks, at the cost of the DWT compared to DCT schemes. Each watermark bit is embedded in various frequency bands and the information of the watermark bit is spread throughout large spatial regions. As a result, the watermarking technique is robust to attacks in both frequency and time domains. The experimental results show the proposed embedding technique can survive the cropping of an image, image enhancement and the JPEG lossy compression. However, improvements in their performance can still be obtained by viewing the image watermarking problem as an optimization problem. In this paper we applied genetic algorithms. By carefully defining the “user key,” multiple watermarking and repeatedly embedding to harden the robustness are available. Our technique could also be applied to the multi resolution image structures with some modification about the choice of middle frequency coefficients.

In this proposed method the values of the PSNRs of the watermarked images are always greater than 40 dB and it can effectively resist common image processing attacks, especially by JPEG compression and low-pass filtering.

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