A WAVELET BASED HYBRID SVD ALGORITHM FOR DIGITAL IMAGE WATERMARKING

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ABSTRACT

In this paper we propose a hybrid image watermarking algorithm which satisfies both imperceptibility and robustness requirements. Our proposed work provide an optimum solution by using 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, Singular value decomposition.

1. INTRODUCTION

Due to the advancement of digital technologies and rapid communication network deployment, a wide variety of multimedia contents have been digitalized [1][2][3]and their distribution or duplication made easy without any reduction in quality through both authorized and unauthorized distribution channels [4][5]. 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 watermarks are used in authentication [6] [7].The fragile watermarks can be embedded in either

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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 [8] [9].

Watermarking techniques can be broadly classified into two categories spatial domain methods and Frequency (transform) domain methods [10]. 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 [11], 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 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 [12][13]. 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 [14] , 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* [15]. 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 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 [16].

The paper is organized as follows. An introduction about the paper is given in Section 1. Wavelet domain watermarking and singular value decomposition used in our proposed work is provided in Section 2.The proposed approach is presented in Section 3. Experimental results are demonstrated in Section 4. Conclusions and scope for future work are drawn in Section 5.

2. WAVELET DOMAIN WATERMARKING AND SINGULAR VALUE DECOMPOSITION

2.1 DIGITAL IMAGE WATERMARKING IN THE WAVELET DOMAIN

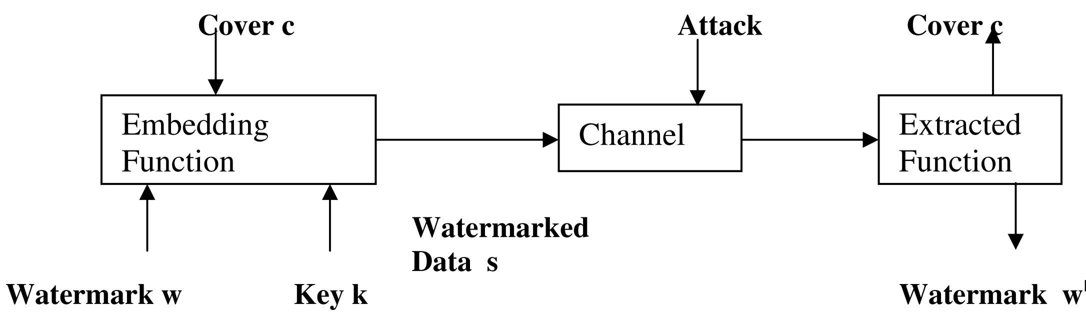
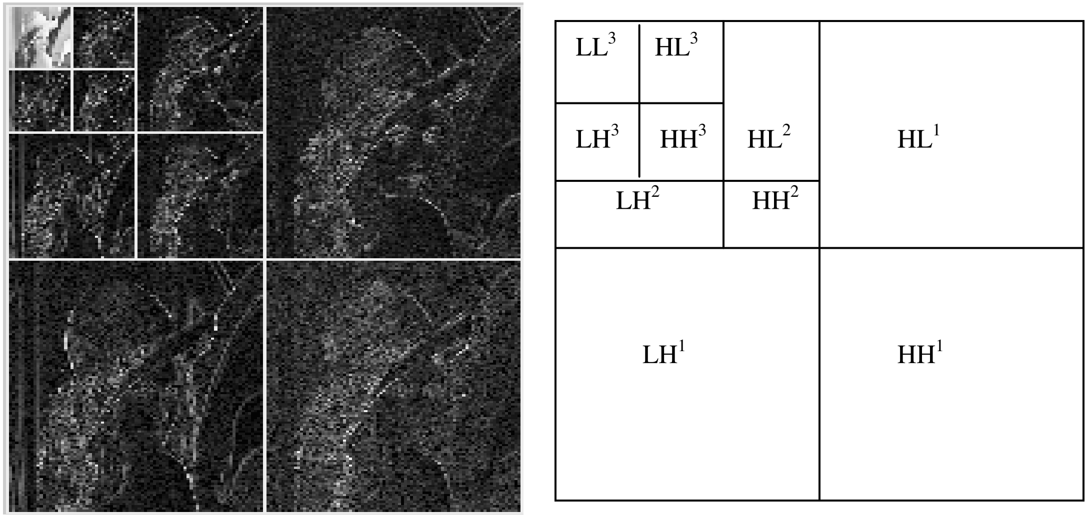


Fig.1. Digital image watermarking framework

All watermarking systems consist of an embedding part and an extraction part as shown in Fig.1. The input to the embedding scheme is the watermark, the cover work and a public or secret key. The cover work can be any multimedia data: audio data, video data or images. The watermark can be a number, text, or an image. The key may be used to enforce security (to prevent unauthorized removal of the watermark). The output is the watermarked work. The recovery part takes the (possibly distorted) watermarked work, the key and/or the original unwatermarked work and returns either the recovered watermark or a confidence measure of how likely a specific watermark is present.

The DWT can be implemented as a multistage transformation. An image is decomposed into four sub bands as shown in Fig.2 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

DWT can be performed on the approximation image many times depending on the requirements needed for the applications. The watermark will be added to the image by modifying the wavelet coefficients. The basic DWT Operation is given by Equation (1).

$$x[n] = (c * w)[n] = \sum_{k=-\infty}^{\infty} c[k]w[n-k] \qquad \text{-------- (1)}$$

The DWT and IDWT can be mathematically given by Equation (2) ,

The DWT consists in splitting the signal $x[n]$ in low and high frequencies using a low pass and a high pass filter respectively:

$$H(\omega) = \sum_{k} h[k]e^{-jk\omega} \quad \text{And} \quad G(\omega) = \sum_{k} g[k]e^{-jk\omega} \qquad \text{--------- (2)}$$

Lahouari Ghouti , Ahmed Bouridane, Mohammad K. Ibrahim and Said Boussakta [17] 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. [19][33].

In order achieve both image authentication and protection simultaneously, Chun-Shien Lu , and Hong-Yuan Mark Liao [20] 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 [21][32].

Though there are existing systems that provides perceptual invisibility and robustness**,** YiweiWang, John F. Doherty & Robert E. Van Dyck [23][34] 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 [24] 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.

Fig.3.Watermark Image

Fig.4.Host Image

Mauro Barni, Franco Bartolini and Alessandro Piva [25][38] 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 [26].

Several watermarking schemes have been proposed to combat geometric attacks. Based on Fourier-Mellin Transform (FMT), Ruanaidh and Pun suggested a watermarking scheme to resist geometric attacks such as rotation, scaling and translation [27][36]. But FMT could degrade image quality seriously. Pereira and Pun proposed that a template besides the watermark was embedded in the original image [28][40]. A potential problem arises when a common template is used for different watermarked images, which makes the method susceptible to collusion-type detection of the template. Based on Zemike transform, Chen et al. developed a method that the watermark is embedded into wavelet domain by modifying the block average. But the method can not resist translation and RST attacks. By modifying Zemike moments with orders lower than 5, Kim et al. proposed a RST invariant watermarking scheme.

T. M. Ng and H. K. Garg [27][35] 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 [28] 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 [30][39] construct the new nontensor product wavelet filter banks, which can capture the singularities in all directions.A novel multipurpose digital image watermarking method [31][40] has been proposed based on the multistage vector quantizer structure, which can be applied to image authentication and copyright protection applications.

To ensure the IDWT and DWT relationship, the orthogonality condition on the filters is used which is given by Equation (3).

$$|H(\omega)|^2 + |G(\omega)|^2 = 1 \qquad \text{---------- (3)}$$

2.2 SINGULAR VALUE DECOMPOSITION

Singular Value Decomposition, SVD is an important linear algebra tool, which is often used in image compression, digital watermark and other signal process fields. A digital image can be composed of many matrixes of non-negative scalars from the aspect of linear algebra.

SVD of an N×N image C is computed as

$$C = USV^T \qquad \text{------------ (4)}$$

Where U, V are N×N unitary matrices ($UU^T=I$, $VV^T=I$), and S is a unique diagonal N×N matrix, (S = diag(s1,s2…,sr ,0,…,0) , where s1 ≥s2 ≥…. sr > 0), known as the singular value (SV) matrix of C .

Watermarking the image C is done by embedding the watermark W into the SV matrix S to form the matrix D = S + aW , where a is a scale factor that controls the strength of the watermark to be embedded in C . SVD is then performed on the new matrix D to obtain U_w, S_w and V_w as

$$D = S + aW \Rightarrow U_w S_w V_w \qquad \text{----------- (5)}$$

3. PROPOSED WORK

3 .1 WATERMARK EMBEDDING

DWT decomposes image into four non overlapping multiresolution sub bands: LL (Approximate sub band), HL (Horizontal sub band), LH (Vertical sub band) and HH (Diagonal Sub band). Here, LL is low frequency component whereas HL, LH and HH are high frequency (detail) components. Modification in the low frequency sub band will cause severe and unacceptable image degradation. Hence watermark is not embedded in LL sub band. The good areas for watermark embedding are high frequency sub bands (HL, LH and HH), because human naked eyes are not sensitive to these sub bands. They yield effective watermarking without being perceived by human eyes. But HH sub band includes edges and textures of the image. Hence HH is also excluded. Most of the watermarking algorithms have been failed to achieve perceptual transparency and robustness simultaneously because these two requirements are conflicting to each other. The rest options are HL and LH. Hence Watermarking done in HL and LH region.

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.5.

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.

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

$$\frac{1}{K}\sum_{i=1}^{P}\left[\left(E_i+\Delta E_i\right)^2-E_i^2\right]=\sigma_i'^2-\sigma_i^2 \qquad \text{------------ (6)}$$

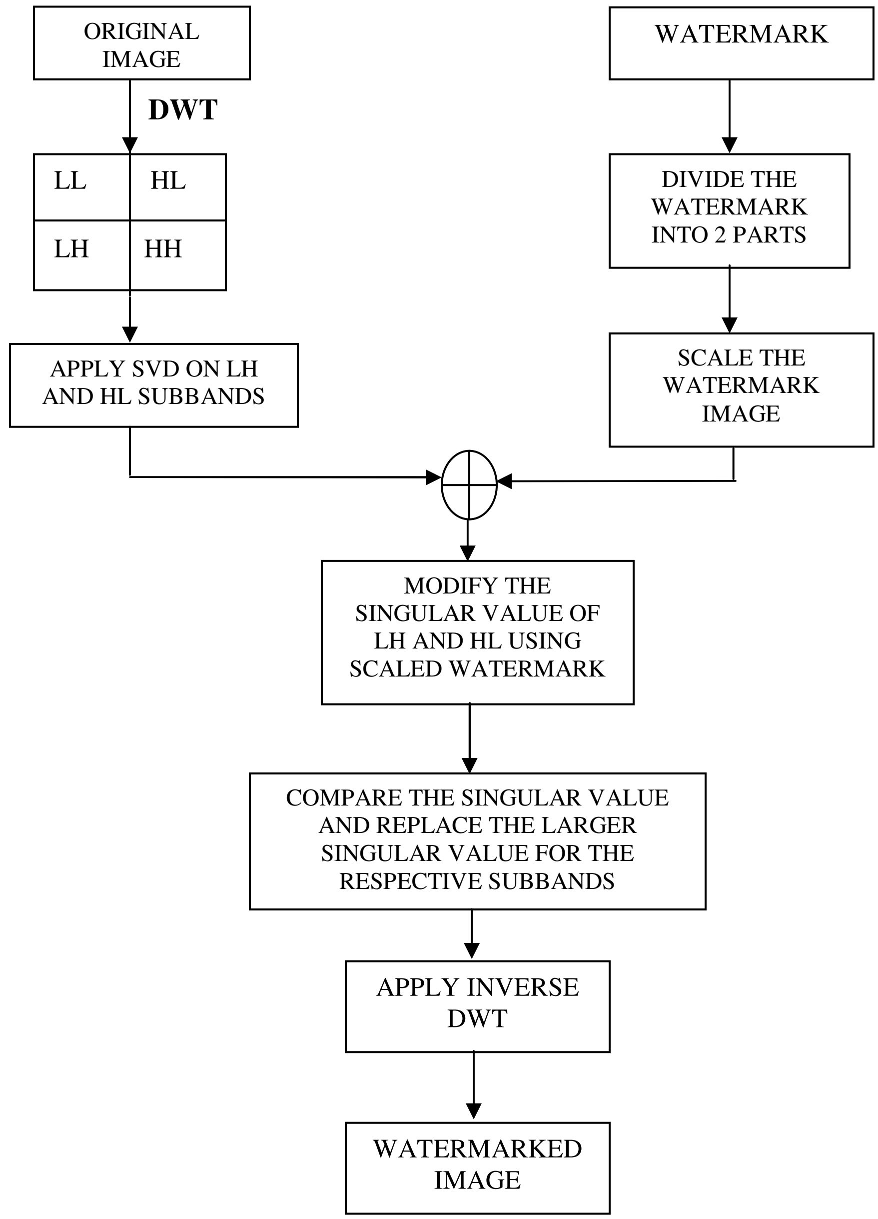


Fig.5. Block Diagram for Watermark Embedding Algorithm

Where ***P*** is the number of coefficients that are modified and ***K*** is the total number of coefficients in the wavelet subspace. Since the modifications of large coefficients E_i, are independent from one another, there are numerous solutions satisfying (6).

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:

$$\sum_{i=1}^{P}\left[E_i(1+\alpha)^2 - E_i^2\right] = K(\sigma_i'^2 - \sigma_i^2) \qquad \text{-------------- (8)}$$

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.6.

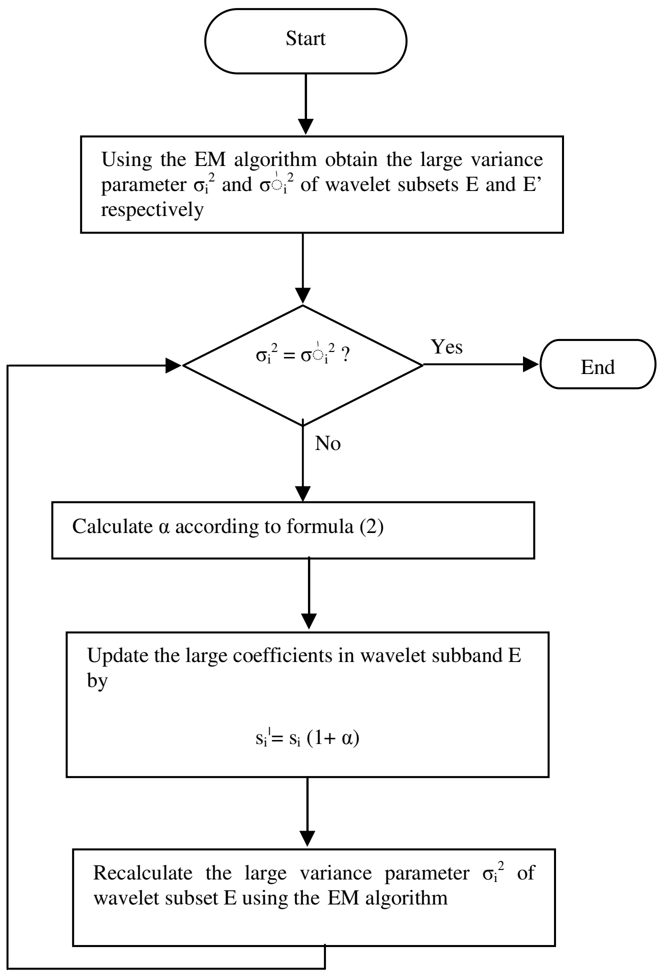


Fig.6. Flowchart for calculating coefficient

3.2 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.7.

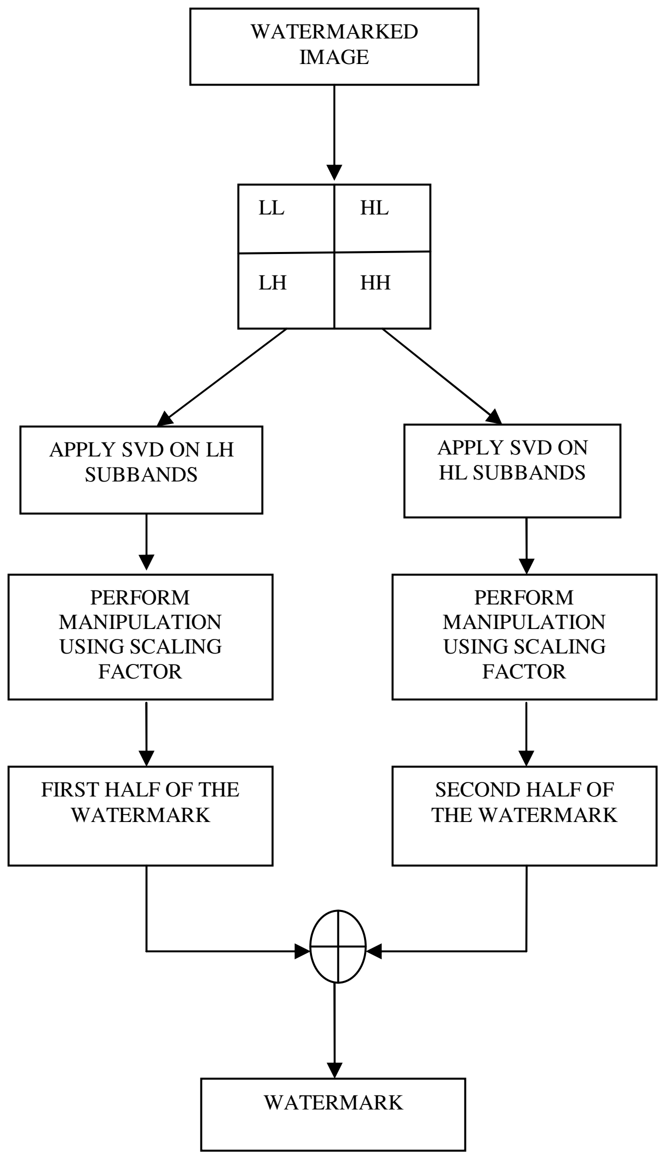


Fig.7. Block Diagram for Watermark Extraction Algorithm

4. EXPERIMENTAL RESULTS

As mentioned earlier, why we are choosing HL and LH sub bands Fig.8. shows that HH sub band has minimum value for original image and same sub band has maximum difference when compared to other two sub bands in the singular values of original and noisy image as shown in Fig.9. Hence watermarking in the HL and LH sub bands doesn't affect the image quality.

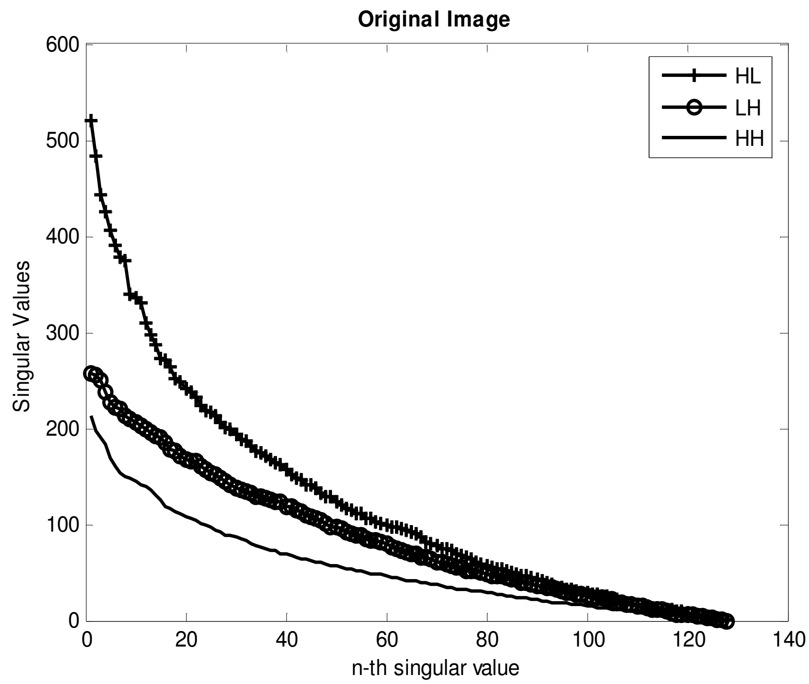


Fig.8.Singular Values of Original Image

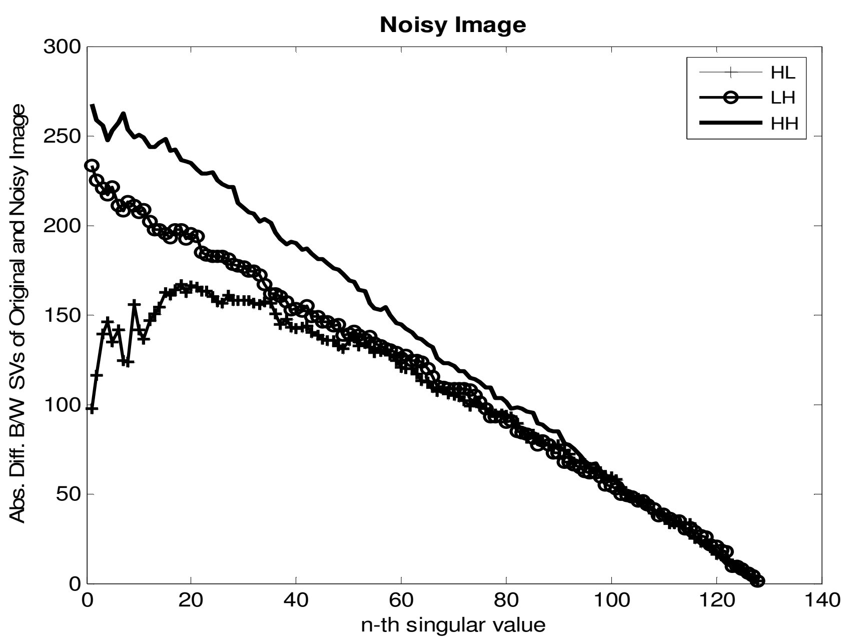


Fig.9. Absolute Difference between SVs of Original and Noisy Image

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.

The error metrics used to test the proposed algorithm are Normalized Cross correlation (NC) and peak signal to noise ratio (PSNR). Let the host image of size *NxN* be $c\ (i, j)$ and the watermarked counterpart be $s(i, j)$, then PSNR in dB is given by

$$PSNR(c,w) = 10log_{10}\left[\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(c(i,j))^2}{\sum_{i=1}^{N}\sum_{j=1}^{N}(s(i,j)-c(i,j))^2}\right] \quad \text{------------- (9)}$$

$$NC = \left[\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i,j)-w_{mean})(w'(i,j)-w'_{mean})}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{N}(w(i,j)-w_{mean})^2\sum^{N}\sum^{N}(w'(i,j)-w'_{mean})^2}}\right] \quad \text{------------ (10)}$$

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

NC (normalized cross-correlation) is used to measure the similarity between the extracted watermark $w^{|}$ and the original watermark *w*.

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.

Fig.10. Original, Watermark and Watermarked image of the Proposed Approach

When the Lena image is added with the Salt and Pepper Noise of density 0.001 and 0.005 the PSNR value is 28.7120 and 28.5280.The Output Image is shown in Fig.11.

Watermarked Image Image with Gaussian Noise Extracted Watermark

Fig.11. Watermarked Image, Image with Gaussian Noise and Extracted Watermark

When the Lena image is added with the Salt and Pepper Noise of density 0.001 and 0.005 the PSNR value is 53.1980 and 48.6342.The Output Image is shown in Fig.12.

Watermarked Image Image with S& P Noise Extracted Watermark

Fig.12. Watermarked Image, Image with Salt and Pepper Noise and Extracted Watermark

When the Lena image is added with the Salt and Pepper Noise of density 0.001 the PSNR value is 31.9924.The Output Image is shown in Fig.13.

Watermarked Image Image with Poisson Noise Extracted Watermark

Fig.13. Watermarked Image, Image with Poisson Noise and Extracted Watermark

Table 1. 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	0.001	0.0030	31.9924

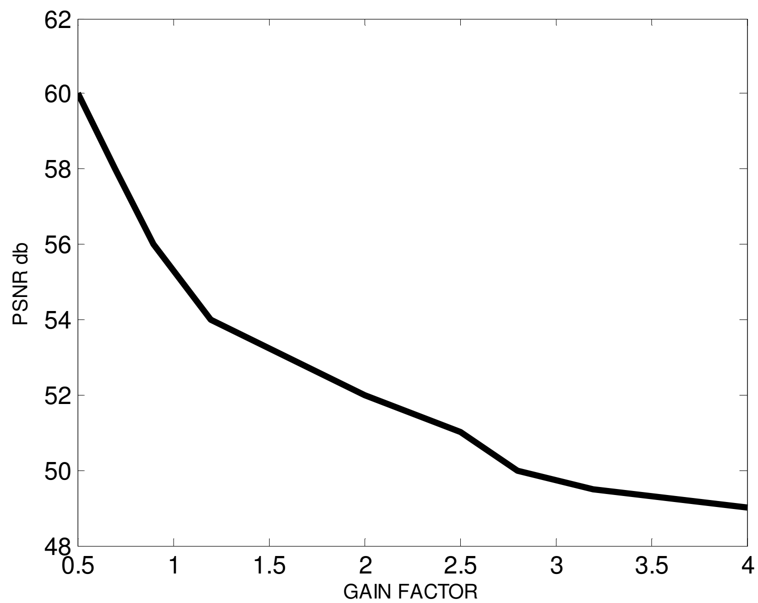


Fig.14. Gain Factor vs PSNR

We observe that the watermarking strength S(I) decreases when the parameter Gain factor ρ increases, see Fig.14. 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:

$$\rho(I) = 0$$
$$S(I) = S(\rho(I), I) \qquad \text{---------------} \ (11)$$

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.

$$S(I)=\max\{S:PSNR(I,)>=45\} \qquad \text{-------------- (12)}$$

5. 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**.** 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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