An Effective Wavelet-Based Watermarking Scheme Using Human Visual System for Protecting Copyrights of Digital Images

V. Padmanabha Reddy and Dr. S. Varadarajan

Abstract—**The modern era of information technology facilitates easy duplication, manipulation and distribution of digital data. This has demanded the certainty for effectively safe guarding the rightful ownership of digital images. Copyright protection and content authentication of digital images have emerged as an imperative concern to content owners and distributors. Digital watermarking provided a potential solution to this issue. The watermarking scheme must possess the characteristics of robustness and imperceptibility to ensure efficient copyright protection. An effective copyright protection is achieved by the incorporation of Human Visual System (HVS) models into watermarking scheme. Recently, interest in watermarking researches are chiefly fascinated by wavelet domain based watermarking schemes. In our earlier work, we have presented an imperceptible and efficient wavelet-based watermarking scheme for protecting the copyrights of images. Here, we have offered a proficient watermarking scheme by effecting some changes to our earlier work. The presented scheme for watermarking incorporates the HVS models into watermark embedding. The biorthogonal wavelet transform with lifting scheme is utilized in the watermarking. The image components for embedding are selected based on the entropy masking. A random matrix is generated on the basis of a key image and is engaged in both embedding and extraction processes. The correlation coefficient computation is made use of in the extraction of watermark. The experimental results illustrate the robustness and imperceptibility of the proposed approach.**

***Index Terms*—Biorthogonal Wavelet Transform, Correlation Coefficient, Copyright Protection, Digital Watermarking, Discrete Wavelet Transform (DWT), Entropy Masking, Human Visual System (HVS), Lifting Scheme, Robust.**

I. Introduction

Nowadays, almost the whole multimedia production and distribution is in the form of digital data [1]. The distribution, replication and modification of digital images are unsophisticated owing to the swift escalation of digital media such as Internet and Compact Discs. Because of this, copyright enforcement methods for the protection of copyright ownership have emerged as critical prerequisites [1], [2].

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On behalf of the content owners and distributors, copyright protection and content authentication of digital content has developed into a grave problem.

This issue can be resolved by the solution offered by the Digital watermarking. In recent times, Digital watermarking has seen rapid escalation [3]. Ownership protection, authentication, and content integrity verification of intellectual property in digital form have comprehensively utilized watermarking, of late [4] [5]. The process of embedding data into multimedia elements such as images, audios and videos is defined as watermarking. The detection or extraction of this embedded data from the multimedia offers the proof of ownership or other purposes [6].

Diverse ways can be employed to find the different classifications of watermarking and watermarking techniques [7]. Generally, the literature available deals with two classes of digital watermarks namely the visible and invisible watermarks. In visible watermarks, the ownership of the image is illustrated by the distinctive unique visible message or a company logo and in the invisible watermarks, the invisibly watermarked digital content and the original image are extremely alike when envisaged [8]. The intent of the design of the major accessible invisible watermarking schemes is to offer either the copyright protection or content authentication. Robust and fragile watermarks are the two extensive categories of the invisible watermarks, the former principally intends at copyright protection where the need for high resistance against numerous signal processing operations is signified by the term “robust”. In contrast, content authentication is the primary objective of the latter [3]. In addition, non-blind, semi-blind and blind methods are the divisions of watermarking. In non-blind methods, the original image itself are employed for the extraction of watermark, while the certain characteristics of the original image are engaged by the semi-blind methods, whereas the detection process in the blind methods do not necessitate the original image [9].

A good watermarking scheme should be robust enough to defend against attacks while being invisible such that the dissimilarity between the watermarked image and the host image should not be distinguishable by the human eyes. On the other hand, the exclusion of the watermark embedded in the host image should not be simple and the quality of the host image should not be spoiled very much [10]. The two classes of the digital image watermarking techniques available in the literature are spatial domain and frequency domain techniques which are typically classified with the domain of watermarking as the basis The spatial domain techniques embed the watermark by altering the pixel values of the original image and the frequency domain techniques embed the watermark in the domain of an invertible transform [11]. The greater parts of the researches embed the watermark in the frequency domain with the purpose improving the robustness [10]. The Discrete Cosine Transform (DCT), the Discrete Wavelet Transform (DWT), the Discrete Fourier Transform (DFT), Discrete Hadamard Transform (DHT), etc are the diverse transformations employed extensively in as substitute for the spatial domain [12], [13]. The computation efficiency of DWT is the inspiration behind its prevalent engagement in the transformation of an image from spatial domain to frequency domain. The numerous researches accessible in the literature utilize DWT for watermarking digital images.

In a number of wavelet-based watermarking schemes, the Human Visual System (HVS) is employed to determine the modifiable wavelet coefficients to embed the watermark which on modification is imperceptible or transparent to human eyes [14], [15], [16]. In general, while the discernible quality of the content is at a sufficient level, the watermark embedded into the original data is allowed to reside. The watermark should accomplish copyright protection in a robust and imperceptible manner. At the same time, there is a disparity among the requirements of imperceptibility and robustness. Intelligent optimization algorithms and HVS based algorithms are the two general types of methods to achieve robustness and imperceptibility [17]. HVS models the sensitivity of the human eyes to the input signal (i.e., how our eyes observe invisibility). So, to keep the visual distortion to minimum and to optimize the watermarking methods it is indispensable to employ the HVS when developing a watermarking system [18], [11]. The HVS model easily personalizes the specified resolution for viewing. The mind does not recognize all the things that we view. The watermark embedded on textures possesses good robustness to general image processing and other attacks because of the exceptional responses of the HVS on textures. A HVS based invisible watermarking technique is developed based on this knowledge [12], [19]. Several HVS model based watermarking techniques are available in the literature [14, 15, 20, 21, 22].

In this paper, we have presented an effective wavelet-based watermarking scheme for protecting copyrights of digital images by making some changes to our earlier work [39]. In the proposed scheme, the human visual system is utilized to determine the image components for embedding watermark data. The proposed watermarking scheme utilizes the characteristics of HVS for embedding the watermark robustly and imperceptibly. The binary watermark image is embedded into the host image in the wavelet domain. A random matrix is produced on the basis of a key image with the aid of the approach employed in the embedding process. Primarily, the host image is decomposed into four sub-bands LL, LH, HL, HH by means of biorthogonal wavelet transform with the lifting scheme. The choice of appropriate sub-band is made based on entropy masking of HVS model. Afterwards, except LL sub-band all the other sub-bands are considered, and for watermark embedding, the sub-band with maximum entropy is selected. Subsequently, the watermark image is embedded into the selected sub-band with the assist of the generated random matrix. At last, the modified sub-band is mapped back into its original position and inverse biorthogonal wavelet transform with lifting scheme is applied to attain the watermarked image.

The watermark extraction necessitates the watermarked image, key image, the embedded sub-band information and the size of watermark image. As conversed in embedding process, to begin with the watermarked image is decomposed into four sub-bands using the biorthogonal wavelet transform with lifting scheme followed by the selection of the sub-band which embeds the and finally the extraction of watermark through the correlation coefficient computation and generated random matrix. As the watermarking is carried out in wavelet domain with the aid of HVS model, the proposed scheme is imperceptible and robust against attacks on image processing. The experiments conducted with attacked host images have verified the robustness of the proposed scheme.

The rest of the paper is organized as follows: Section II presents a concise review of some of the recent researches in watermarking that incorporate HVS for copyright protection of digital images. Section III and Section IV illustrates the basics of Human Visual System and its application in watermarking and biorthogonal wavelet transform with lifting scheme respectively. The proposed effective wavelet-based watermarking scheme using human visual system for protecting copyrights of digital images is described in Section V. Section VI presents the experimental results and analysis of the proposed watermarking scheme and the conclusions are summed up in Section VII.

II. Review of Existing Works on Watermarking for Copyright Protection

Our work has been motivated by several earlier works in the literature associated to watermarking for copyright protection of digital images. A concise description of a few of the current researches is mentioned below:

Intended for the copyright protection a digital watermarking technique was developed by Xiaojun Qi [20]. By means of the qualified significant wavelet coefficients and the texture and luminance content between two diverse coarse scales (level 2 and level 3 wavelet decompositions) they deliberated to adaptively implement the digital watermark by means of finding out the positions and magnitudes. Through the approach to put out of sight a robust watermark in an efficient manner the characteristics of the human visual system are downtrodden. With the purpose of identifying the watermark the correlation coefficients across the wavelet coefficients as well as the watermarking code at level 2 and level 3 together with the stored side information are compared. By means of the experimental results the robustness of their method in opposition to JPEG compression in addition to various image processing techniques was demonstrated.

Ching-Sheng Hsu and Shu-Fen Tu [10] developed an indiscernible wavelet-based watermarking scheme. By implementing the variation it has been defined by them the degree of transparence of coefficients of LL band. Soon after, in order to embed the coefficients of HL3 and LH3 bands were identified. The modular operation is also been implemented in watermark embedding phase. Besides, the robustness of their method in opposition to most attacks was demonstrated as well as the watermarked image was highly unrevealed in nature.

Franco A. Del Colle and Juan Carlos Gomez [23] developed an Image Adaptive watermarking method on the basis of the Discrete Wavelet Transform. For judging against the estimated robustness and fidelity of their method state-of-art watermarking techniques are utilized. An image fidelity factor on the basis of a perceptual distortion metric is established so as to calculate the transparency of the watermark. On the other hand, they intended to assess the robustness of the watermark in opposition to JPEG compression and resizing by setting up a degradation factor. By the fidelity metric a perceptually aware objective quantification of image fidelity is allowed. By means of the preliminary results they demonstrated a good correlation of the metric with the subjective assessment.

Nizar Sakr *et al.* [24] presented an adaptive watermarking algorithm which makes use of a biorthogonal wavelets-based human visual system as well as a Fuzzy Interference System (FIS) intending in order to preserve the copyright of images in learning object repositories. A well-organized extraction of the masking information by HVS relies upon the linear-phase property of biorthogonal wavelet filters (symmetric wavelets) which offers that the local characteristics of the image are taken into account. FIS was made use with the intention of calculating the most favorable watermark weighting function that would facilitate the implantation of the maximum-energy and imperceptible watermark. Both signal processing and geometric attacks are handled by the algorithm in an efficient manner.

John N. Ellinas and Panagiotis Kenterlis [11] offered a method for image watermarking. With the intention of implanting the watermarking data on selected wavelet coefficients of the input image the CSF characteristics of the HVS are taken into account. The chosen coefficients dwell on the detail sub bands as well as the information regarding the edges of the image were enclosed in them. For this reason, the implanted information becomes invisible by making use of the HVS which was less sensitive to alterations on high frequencies. From the outcome of the experiments conducted the success of their method in terms of robustness and transparency was demonstrated. Their approach performed against the different widespread signal processing methods as compression, filtering, noise and cropping splendidly.

Mohammad Ali Akhaee *et al.* [25] have offered an image-adaptive watermarking system which is on the basis of scaling which make use of human visual model for adapting the watermark data to local properties of the host image. The reason hidden behind the improved performance is embedding in the low-frequency wavelet coefficients and optimal control of its strength factor from HVS point of view. The employment of the Maximum Likelihood (ML) decoder is made possible by the channel side information. It is made clear from the experimental results that the judgment against the other existing watermarking methods, the method was imperceptible and exceedingly robust in opposition to attacks.

Shang-Lin Hsieh *et al.* [26] offered a digital watermarking scheme for copyright protection against piracy of color images. With the purpose of improving the forbearance to attacks, their approach encoded the watermark prior to watermark embedding. In the proposed scheme the feature taken out from the host image by the discrete wavelet transform was used with secret sharing scheme. Moreover, their methodology automatically calculates the scaling factor for diverse images despite the fact that preserving robustness and imperceptibility which is different from other watermarking schemes that necessitate manual adjustment in the embedding scaling factors to set in the watermark. The resistance of their approach against several attacks including cropping, scaling, and JPEG compression is demonstrated.

Zhang Rong-Yue *et al.* [27] offered an adaptive image watermarking algorithm which is on the basis of HMM in wavelet domain. The algorithm has taken into account both the energy correlation across the scale as well as the different sub bands at the same level of the wavelet pyramid and employed a vector HMM model. The embedding strategy is optimized, anticipated for the HMM tree structure. By making use of the dynamical threshold schemes they have improved the performance. The performance of the HMM based watermarking algorithm against Stir mark attacks, for instance JPEG compression, adding noise, median cut and filter was radically made better.

Zolghadrasli and S. Rezazadeh [21] provided a multi-resolution watermarking method on the basis of the discrete wavelet transform for copyright protection of digital images. The watermark which is implemented is a noise type Gaussian sequence. By taking into account the human visual system so as to embed the watermark robustly and imperceptibly watermark components are added to the important coefficients of each selected sub band. By carrying out some small modifications the HVS model is improved. The extraction of the watermark concerned the host image. By means of the Normalized Correlation function the similarities of the extracted watermarks are calculated. The robustness of their method in opposition to extensive variety of attacks was demonstrated.

Shiva Zaboli *et al.* [1] offered an entropy-based method for non-blind watermarking of still gray level images by means of discrete wavelet transform. Additionally, the embedding phase of their watermarking algorithm employed the Discrete Wavelet Transform (DWT) feature and Human Visual System (HVS) characteristic. The performance of their method is improved when compared with the renowned DWT based methods and in opposition to the existence attacks in literature.

III. UMAN VISUAL SYSTEM (HVS) IN WATERMARKING

The human visual system plays a significant part in digital image processing. In 1974, Mannos and Sakrison established the HVS model for the first time [28]. Numerous researchers have been conducting studies on the HVS [29], [30]. The HVS is a nonlinear and spatially varying system [19]. The design specifications of HVS are simplicity, visual sensitivity and selectivity to model and enhance perceived image quality. The HVS is based on the psychophysical process, which relates psychological phenomena (contrast and brightness etc.) to physical phenomena (light sensitivity, spatial frequency and wavelength etc.). The majority of HVS models in image processing make use of three basic properties of human vision: frequency sensitivity, luminance sensitivity and masking effects. The frequency sensitivity determines the sensitivity of human eye to various spatial frequencies. The luminance sensitivity calculates the effect of the detectability threshold of noise on a constant background. The frequency sensitivity is corrected based on the change of background luminance. The effect of decreasing visibility of one signal in the existence of another signal called masker is known as masking [22].

Copious numbers of HVS models have been developed for attaining the objectives of quality assessment or image compression [31]. In addition, digital watermarking of images can be achieved by employing similar visual models. Robustness, perceptual transparency and capacity are the three basic necessities of digital watermarking techniques but there exists a disagreement amongst these necessities. The integration of HVS into watermarking process can aid in fulfilling these conflicting requirements. The functions of the HVS models incorporated into watermarking are: Selection of perceptually significant image components for watermark embedding and scaling of watermark elements before embedding into original data [22]. There are several HVS model based watermarking techniques available in the literature [14, 15, 20, 21, 22].

The entropy masking of HVS model is employed for watermark embedding process in our scheme. High entropy regions of an image exhibit higher complexity and uncertainty, and if an image contains a lot of redundancy in its pixel values the image is said to have weak entropy and vice versa [32]. Higher entropy area modifications are very difficult to be recognized by the human eye owing to this higher complexity [6]. The selection of image components with high entropy value for watermark embedding is based on the above property.

IV. BIORTHOGONAL WAVELET TRANSFORM WITH LIFTING SCHEME

The biorthogonal wavelet transforms are invertible transforms with the properties of perfect reconstruction and symmetric wavelet functions. The biorthogonal wavelets acquire those properties as they possess two sets of low-pass filters (for reconstruction), and high-pass filters (for decomposition). Each set is the dual of the other. In the contrary, the orthogonal wavelets comprises of only one set. In biorthogonal wavelets, the decomposition and reconstruction filters are attained from two dissimilar scaling functions with regard to two multi resolution analyses in duality. Higher embedding capacity when utilized in the decomposition of the image into diverse channels is a special beneficial characteristic of biorthogonal wavelets when compared with orthogonal wavelets [33], [35]. The aforementioned biorthogonal wavelet characteristics make them potential candidates in the wavelet domain.

Biorthogonal wavelets initiate two wavelets. One of them, φ aids in the analysis while the other ψ , aids in synthesis as is found in (a) and (b) respectively.

$$C_{j,k} = \int s(x)\varphi_{j,k}(x)dx$$

$$s = \sum_{j,k} C_{j,k}\psi_{j,k}$$

Here, s represents the signal while j,k are integers.

Wim Sweldens introduced the lifting scheme [34] for improving the conventional DWT's computational speed and the digital design in an efficient manner [36]. The pros of the lifting scheme when compared with the classical wavelet transform are the features such as: Generic Method, Easily understandable and implemental, faster, the inverse transform is easier to find, lesser memory required for in-place computation, usage on arbitrary geometrics, application on irregular samplings, extendable for weighting functions and simple extension to an integer transform. The lifting scheme can be utilized for the any wavelet filter implementation. The wavelet transform using lifting scheme produces all sub-band data in an interleaved form ('in-place' transform) [37].

V. THE PROPOSED EFFECTIVE WATERMARKING SCHEME

This section describes the scheme proposed for achieving effective watermarking. For watermark embedding, the selection of appropriate image components is made based on the entropy masking of HVS model. Biorthogonal wavelet transform with lifting scheme is employed for performing watermarking in the wavelet domain. For being employed in the embedding process, a random matrix is generated by means of a key image. The watermark extraction process necessitates the watermarked image, key image, size of watermark image and the information about the watermark embedded sub-band. In addition, the correlation coefficient computation and generated random matrix are also made use of in the extraction process. The following sub-sections explain the steps involved in the watermark embedding and extraction.

A. Watermark Embedding

This sub-section presents the process of embedding the watermark image into the host image. The watermark image chosen in our proposed scheme is a binary image and the host image must be dyadic (2^nx2^n) in size. The embedding process is carried out by means of biorthogonal wavelet transform with lifting scheme in the wavelet domain. Firstly, biorthogonal wavelet transform with lifting scheme is used to decompose the host image into four sub-bands LL, LH, HL and HH. Subsequently, the entropy values of the LH, HL, and HH sub-bands are computed and for watermark embedding the sub-band with maximum entropy value is selected. On the basis of a key image, the random matrix is generated. Consequently, sub-band is chosen from host image to embed the binary watermark image. The generated random matrix and the embedding strength β are employed to embed the binary watermark into the host image. Lastly, sub-band embedded with the watermark is mapped back into its original position and inverse transform is applied to obtain the watermarked image. The block diagram of the watermark embedding process is shown in Fig. 1.

Steps in Watermark Embedding Process:

Input: Host Image (I), Binary Watermark Image (W), Key Image (I_k)

Output: Watermarked Image (I_W)

1) Decomposition of the host Image I into four sub-bands using Bi-orthogonal wavelet transform with lifting scheme.
2) Calculation of the entropy masking of all sub-bands except LL sub-band. The entropy value of a sub-band is computed with the following equation.

$$E = -sum(p.*\log(p))$$

Where p contains the count of the histograms.

3) Choice of a sub-band with maximum entropy value from the three sub-bands (LH, HL, HH) for embedding the watermark image (W) and is denoted as I_M .
4) Generation of an initial random matrix R :
   (i) Summation of the pixel values in the key image (I_k). The summed values are denoted as R_{seed} .

$$R_{seed} = \sum_{i=1}^{n} \sum_{j=1}^{n} I_{k_{ij}}$$

   (ii) Creation of a random matrix R of selected sub-band's size with the R_{seed} value as seed value of the pseudo random matrix generator. For the image's size of 2^n x 2^n, the sub-band's size will be ($2^n/2$ x $2^n/2$).

$$R = PRMG[R_{seed}]_{(2^n/2 \times 2^n/2)}$$

5) Generation of a final random matrix RM by means of R :
   (i) Subtract 0.5 from the generated random matrix R and multiply the resultant matrix by 2. Let R_t denote the final resultant matrix.

$$R_t = (R - 0.5) \times 2$$

   (ii) At last, a Pseudo random matrix generator with R_t matrix as seed value is used to generate the final random matrix RM .

$$RM = PRMG[R_t]_{(2^n/2 \times 2^n/2)}$$

6) The embedding process of the binary watermark image pixels into the selected sub-band is described next. For embedding pixel value '0', multiply the random matrix RM with the embedding strength β and add the resultant matrix with the selected sub-band I_M values. For pixel value '1', no changes are effected. The aforementioned process is symbolized as follows.

$$[I_M] = [I_M] + (\beta * [RM]) \quad ; \; where\, \beta = 2$$

7) The steps 5 and 6 are repeated until all the watermark pixels are embedded. For every iteration, $PRMG$ initiated with seed R_{seed} generates the initial random matrix R .
8) Mapping of the modified sub-band (I_M) back to its original position and application of inverse Bi-orthogonal wavelet transform with lifting scheme to attain the watermarked image I_W .

B. Watermark Extraction

This sub-section explains the extraction of watermark image from the watermarked image. The watermarked image, size of watermark image, key image and the information about the sub-band in which the watermark has been embedded are essential for the extraction of the watermark image. Initially, a random matrix is generated from the key image by the steps discussed in the previous sub-section. Subsequently, the watermark pixels are extracted with the aid of correlation coefficient computation and the random matrix generated. The block diagram of the watermark extraction process is portrayed in Fig 2. ***Steps in Watermark Extraction Process:***

Input: Watermarked Image (I_W) , Size of Watermark Image $(|W|)$, Key Image (I_k), Sub-band information.

Output: Watermark Image (W).

1) Decomposition of the watermarked image (I_W) using Bi-orthogonal wavelet transform with lifting scheme and selection of the watermark embedded sub-band (I_M) based on the sub-band information.
2) Generation of the random matrix RM employing the steps (4 and 5) cited in the previous sub-section. Similarly, for every iteration the initial random matrix R is generated from the $PRMG$ initiated with seed R_{seed} .
3) Computation of the correlation coefficient (r) between the sub-band (I_M) and the generated random matrix [RM]:

$$r = \frac{\sum_m \sum_n (A_{mn} - \bar{A})(B_{mn} - \bar{B})}{\sqrt{\left(\sum_m \sum_n (A_{mn} - \bar{A})^2\right)\left(\sum_m \sum_n (B_{mn} - \bar{B})^2\right)}}$$

Where,

$$A_{mn} \rightarrow \text{sub-band} \;\; (\mathrm{I_M})$$

$$B_{mn} \rightarrow Random \text{ Matrix}[\text{RM}]$$
$$\overline{A} \rightarrow Mean\ value\ of\ A$$
$$\overline{B} \rightarrow Mean \text{ value of B}$$

4) Division operation is applied on the calculated correlation coefficient value (r) by two and the resultant value is represented as R_V .

$$R_V = r/2\,;$$

5) The steps 2 to 4 are repeated for the size of watermark image $|W|$ and the resultant values R_V are stored in a vector VR_V .

6) Calculation of the vector VR_V 's mean value.

$$\overline{VR}_v = \sum_{i=1}^{k} VR_v^i \Big/ k \qquad ;\ where\ \text{k} = |\text{VR}_{\text{v}}|$$

7) Comparison of the elements of the vector VR_V against the mean value $\overline{VR}_v$ for the extracting the watermark image pixels. If the VR_V 's element value is greater than the mean value, the extracted watermark image pixel is '0' else the pixel value is '1'. The corresponding equation for the above process is,

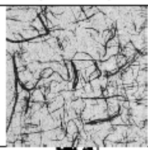
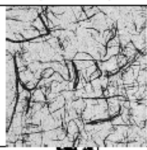
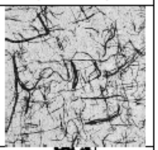
$$W(x,y) = \begin{cases} 0, & VR_v^i > \overline{V}R_v \\ 1, & Otherwise \end{cases} \quad ;\ where\ \text{n} = |\text{VR}_{\text{v}}|$$

8) Ultimately, place the pixel values extracted in a matrix of the size of watermark image to attain the watermark image (I_W) .

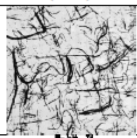
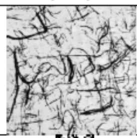
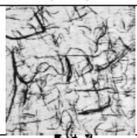
VI. Experimental Results

This section presents the proposed watermarking scheme's experimental results and analysis. The proposed watermarking scheme is programmed in Matlab (Matlab 7.4). The experiments are performed with the texture images obtained from Brodatz Texture Image database [38]. The texture images in the database are of size 640 x 640. An image of size 35 x 1 is chosen as the key image. The proposed scheme successfully generated the random matrix from the key image. The technique discussed in the paper effectively embedded the watermark image into the host image and extracted it back from the watermarked image. The watermarked images possess superior Peak Signal to Noise Ratio (PSNR) and visual quality. Fig. 3 depicts the watermark and watermarked images of three different host images with their respective PSNR values.

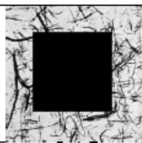
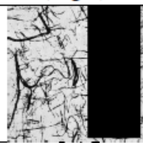
In order to prove the robustness of the proposed watermarking scheme, we have carried out a range of attacks on watermarked images in our experiments. Fig. 4 shows the results of different image attacks such as Gaussian blur, Gaussian noise, Gaussian filter, Wiener filter, Sharpening, Cropping, Intensity value adjustment along with their extracted watermark images and correlation coefficients calculated between the original watermark and the extracted watermark from the attacked watermarked images. The experimental results demonstrate that the correlation coefficient's value is above 0.3. The robustness of the proposed scheme is evident from the experimental evaluation.

Attack	Sharpening (α = 0.4)	Sharpening (α = 0.7)	Sharpening (α = 0.9)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	1	0.9975	0.8992

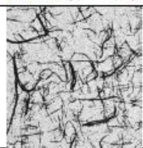
(a)

Attack	Weiner Filtering (2x2)	Weiner Filtering (4x4)	Weiner Filtering (4x8)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	0.8966	0.7207	0.8672

(b)

Attack	Cropping (Left Upper)	Cropping (Middle)	Cropping (Right)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	1	0.9961	0.9941

(c)

Attack	Gaussian Noise (σ = 25)	Gaussian Noise (σ = 50)	Gaussian Noise (σ = 100)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	1	0.9727	0.8673

(d)

Attack	Gaussian Blur (length= 2, θ =8)	Gaussian Blur (length=2, θ =10)	Gaussian Blur (length=3, θ =12)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	0.7755	0.7813	0.3215

(e)

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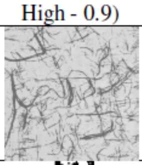
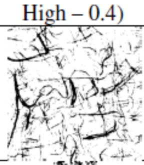
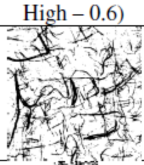
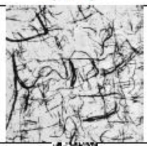
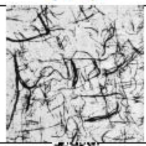
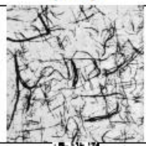
Attack	Intensity Adjustment (Low – 0.4, High - 0.9)	Intensity Adjustment (Low - 0.2 , High – 0.4)	Intensity Adjustment (Low - 0.4 , High – 0.6)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	1	0.7011	0.6191

(f)

Attack	Gaussian Filter (2x2)	Gaussian Filter (3x2)	Gaussian Filter (3x3)
Attacked Images			
Extracted Watermark			
Correlation Coefficient	0.4294	0.4099	0.7931

(g)

Fig.4 Attacked watermarked Images, Extracted watermark image and correlation coefficient of (a) Sharpening (b) Wiener Filter (c) Cropping (d) Gaussian Noise (e) Gaussian Blur (f) Intensity Adjustment (g) Gaussian Filter Attacks

VII. Conclusion

The unauthorized exploitation of digital images has initiated the critical need for the copyright enforcement techniques that serve in the protection of copyright ownership. In this paper, we have presented an effective wavelet-based watermarking scheme using human visual system for protecting copyrights of digital images. The watermarking has been performed in wavelet domain with the aid of biorthogonal wavelet transform with lifting scheme. The incorporation of HVS model into the proposed scheme has enabled the creation of an efficient watermarking scheme for effective copyright protection of images. The entropy masking of HVS model has been utilized for the selection of image components suitable for embedding. A random matrix was generated by using a key image and was made use of in the proposed watermarking scheme. The correlation coefficient computation has been made use of in the extraction process. The proposed scheme has met both the requirements for effective copyright protection scheme: imperceptibility and robustness. The experimental results have demonstrated the efficiency and robustness of the proposed scheme with the aid of attacks.

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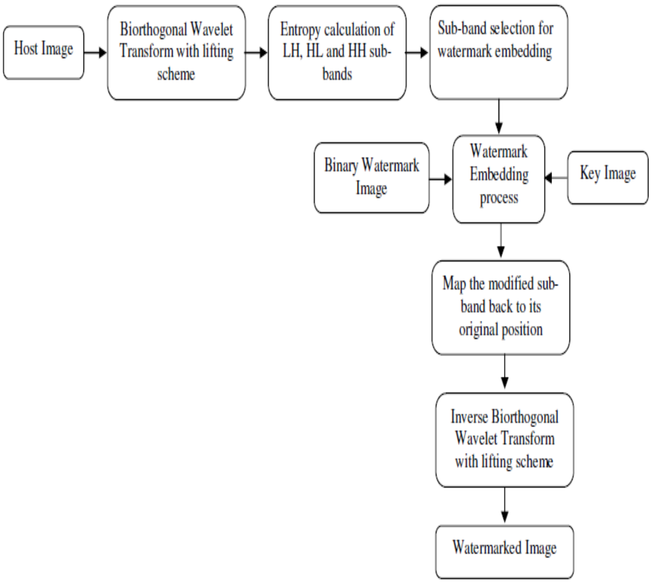


Fig.1 Watermark Embedding Process

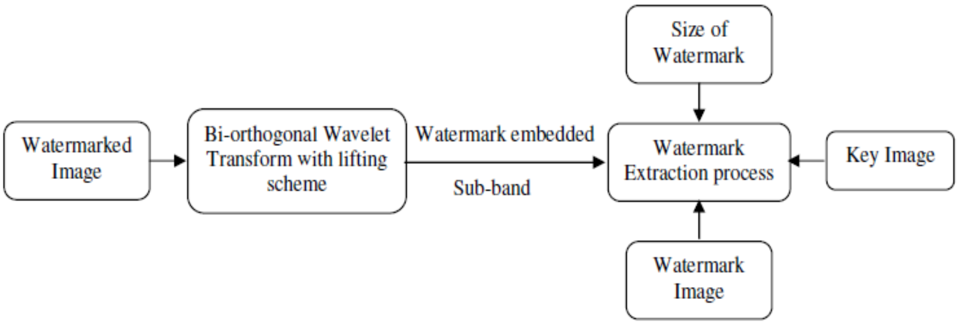


Fig.2 Watermark Extraction Process

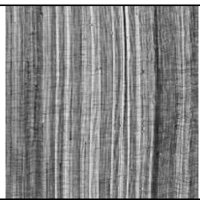
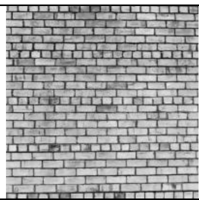
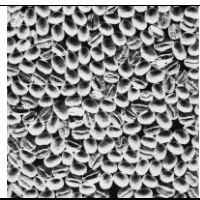
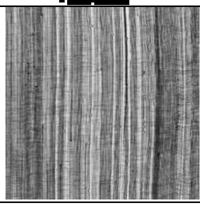
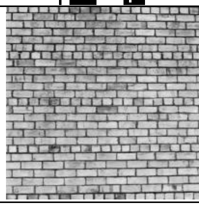
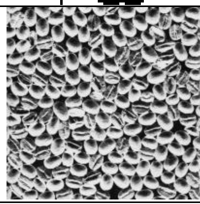
	Texture 1	Texture 2	Texture 3
Host Image			
Watermark Image			
Watermarked Image			
PSNR (dB)	29.4254	29.7903	29.7329

Fig.3 (a) Host Image (b) Watermark image (c) Watermarked Image with PSNR value