A Robust Multiwavelet-Based Watermarking Scheme for Copyright Protection of Digital Images using Human Visual System

Padmanabhareddy Vundela[1] and Varadarajan Sourirajan[2]
[1]Department of Information Technology, Vardhaman College of Engineering, India
[2]Department of Electrical and Electronic Engineering, S.V. University College of Engineering, India

Abstract: *The contemporary period of information technology facilitates simple duplication, manipulation and distribution of digital data. This enduringly, has insisted the rightful ownership of digital images to be protected efficiently. For content owners and distributors, there emerged a necessary concern in regard to the content authentication of digital images as well as copyright protection. A latent solution to this issue is bestowed by digital watermarking. To certify efficient copyright protection, the watermarking scheme should own the characteristics, such as robustness and imperceptibility. Integration of Human Visual System (HVS) models with in the watermarking scheme helps to attain an effective copyright protection. Currently, wavelet domain based watermarking scheme mainly interested in watermarking researches. An undetectable and proficient wavelet-based watermarking scheme to safe guard the copyrights of images are portrayed here on contrary to the prior works. By effecting few modifications to our prior works, we have presented a new proficient watermarking scheme by incorporating the HVS models for watermark embedding. Additionally, we have applied the GHM multiwavelet transform in the watermarking process. Based on the computed distance using hausdorff distance measure, the image components for embedding are selected and a new procedure is designed for watermark embedding by multiplying the embedding strength with the random matrix that is generated by key image as a primary element and is engaged in both embedding and extraction processes. The correlation coefficient computation is used for extraction of watermark process. The experimental results illustrate the robustness and imperceptibility of the proposed approach. From the results, we can identify that the proposed watermarking process has achieved the correlation value of 0.9848 even if the watermarked image is affected by the Gaussian noise.*

Keywords: *Digital watermarking, copyright protection, HVS, robust, discrete wavelet transform, GHM multiwavelet transform, canny edge detection algorithm, hausdorff distance measure, correlation coefficient.*

Received November 15, 2010; accepted May 24, 2011; published online August 5, 2012

1. Introduction

Currently, the entire multimedia production and distribution is represented using digital data. Due to the speedy acceleration of digital media`s, the distribution, replication and modification of digital images are being unsophisticated. On account of this, copyright enforcement methods for the protection of copyright ownership were aroused as detracting rudiments [36]. Copyright protection and content authentication of digital content, has grown into a serious threat preferably because of the content owners and distributors. This issue can be resolved by the solution offered by the digital watermarking. In topical decades, a rapid escalation has been seen on digital watermarking [2, 10, 20]. Currently, watermarking is comprehensively utilized for ownership protection, authentication, and content integrity verification of intellectual property in digital representation [17]. 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 provides the evidence of ownership or other purposes [26].

Different classifications of watermarking and watermarking techniques can be identified by employing various ways [19]. In general, the presented literature deals with two classes of digital watermarks namely the visible and invisible watermarks. In visible watermarks, by means of the distinctive unique visible message or a company logo, the ownership of the image is being illustrated and in the invisible watermarks, when viewed, both the invisibly watermarked digital content and the original image are intensely similar [16]. The two widespread classes of the invisible watermarks are robust and fragile watermarks; the former predominantly aims at copyright protection where the necessity for high resistance against plentiful signal processing operations is implied by the term “robust”. In disparity to the first one, the primary objective of the other one is content authentication [29]. Additionally, watermarking gets divided into the following categories non-blind, semi-blind and blind methods. In non-blind methods, to extract the watermark the original image itself is being employed, while the semi-blind methods engages particular characteristics of the original image, in exception of the other two cases, the detection process in the blind methods do not necessarily requires the original image [9, 14]. To progress the robustness, majority of the researches, embed the watermark in the frequency domain [13]. As a substitute for the spatial domain, diverse transformations widely employed are of the Discrete Cosine Transform (DCT), the Discrete Wavelet Transform (DWT), the Discrete Fourier Transform (DFT), Discrete Hadamard Transform (DHT) and more [6, 8, 24].

Some wavelet-based watermarking schemes use Human Visual System (HVS) to identify which wavelet coefficients can be altered to embed the watermark so, that the modification is imperceptible or transparent to human eyes [11, 34, 37]. The sensitivity of the human eyes to the input signal is being modeled by HVS (i.e., how a human eyes have the ability to view invisibility). While creating a watermarking system, it is essential to get hold of HVS, so that visual distortion is kept to lowest level as well the watermarking methods get optimized [6]. To view an object, a HVS model easily adapts to the specified resolution. It's not necessary that everything observed by the eyes should be perceived by the mind. The watermark embedded on textures has fine robustness to common image processing and other attacks, since the HVS has special responses on textures. Therefore to design a HVS based invisible watermarking technique, this knowledge is being utilized [31, 32]. In the literature, copious HVS model based watermarking techniques are present [7].

In this paper, we have presented an effective wavelet-based watermarking scheme for protecting copyrights of digital images by adding some modifications to our prior works [21, 22]. In the proposed scheme, the HVS is utilized to determine the image components for embedding the watermark data. 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 employed in the embedding process. Primarily, the host image is decomposed into four sub-bands A, H, V and D by means of GHM multiwavelet transform. The edges of all the sub-bands except the A sub-band are detected by canny edge detection algorithm. The choice of appropriate sub-band is made based on the Hausdorff Distance (HD) measure. Subsequently, the watermark image is embedded into the selected sub-band with the support of the generated random matrix. At last, the modified sub-band is mapped back into its original position and inverse GHM multiwavelet transform 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 GHM multiwavelet transform followed by the selection of the sub-band, which embeds the watermark image. Towards the end of the process, the extraction of watermark is done through the calculated correlation coefficient and previously 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 main contributions of the paper are given as follows:

- Incorporated the multi-wavelet transform with HVS model to watermark embedding process.
- Designed a new procedure for watermark embedding by multiplying the embedding strength with the random matrix.
- Extraction procure is carried out based on the correlation co-efficient and mean value.
- Analyze the performance of the proposed embedding procedure using PSNR and NC with various attacks.

The rest of the paper is organized as follows: Section 2 presents a concise review of some of the recent researches in watermarking that incorporate HVS for copyright protection of digital images. Sections 3 and 4 illustrate the fundamentals of HVS and its application in watermarking and the techniques used in the proposed scheme respectively. The proposed effective wavelet-based watermarking scheme using HVS for protecting copyrights of digital images is described in section 5. Section 6 presents the experimental results and analysis of the proposed watermarking scheme and the conclusions are summed up in section 7.

2. Review of Existing Works on Watermarking for Copyright Protection

Numerous prior works in the literature associated to watermarking for copyright protection of digital images stimulates our work. A concise description of few researches is mentioned below:

An imperceptible wavelet-based watermarking scheme was projected by Hsu and Tu [9]. In the scheme, so as to delineate the degree of transparence of coefficients of LL band, they utilized variation, as well as establish transparent coefficients of HL3 and LH3 bands. After that, embed the watermark into those established coefficients. Additionally, during watermark embedding, the modular operation is being used. Some frequent attacks on the watermarked image are simulated during experimentation.

Based on the DWT, an image adaptive watermarking method was proposed by Colle and Gomez [3]. In their work, they have contrasted to stateof-the-art watermarking techniques available in the literature and the robustness and fidelity of the proposed method are also, being evaluated. An image fidelity factor on the basis of a perceptual distortion metric is acquainted to assess the watermark transparency. Simulation results reinforce the appropriateness of the proposed metric for the fidelity evaluation of still image watermarking.

Sakr *et al.* [27], proposed an adaptive watermarking algorithm that uses a bi-orthogonal wavelets-based HVS and a Fuzzy Inference System (FIS) to safeguard the copyright of images in learning object repositories. To proficiently extract the masking information by considering the local characteristics of the image, the HVS in particular relay upon the linear-phase property of bi-orthogonal wavelet filters (symmetric wavelets). To calculate the optimum watermark weighting function which enable the embedding of the maximum-energy and imperceptible watermark, is done using the FIS. The proposed algorithm is robust against both, signal processing and geometric attacks and demonstrated using achieved experimental results.

Image watermarking method was presented by Ellinas and Kenterlis [6]. By taking in regard the CSF characteristics of the HVS, the method embeds the watermarking data on chosen wavelet coefficients of the input image. The chosen coefficients are inherently present on the detail subbands and also, detect the edges of the image. Therefore, the embedded information becomes invisible due to the usage of HVS, which is less sensitive to changes on high frequencies. A finer performance is revealed while concentrating on invisibility and robustness during the evaluation of the proposed method.

To adapt the watermark data to local properties of the host image, Akhaee *et al.* [1], have presented a scaling based image-adaptive watermarking system that make use of human visual model. The following are the reasons that serves to improve its robustness; embedding in the low-frequency wavelet coefficients and optimal control of its strength factor from HVS point of view. Experimental results confirmed the imperceptibility of the method and its higher robustness against attacks compared to alternative existing watermarking methods.

Yue *et al.* [35], presented an adaptive image watermarking algorithm based on Hidden Markov Model (HMM) in wavelet domain. The algorithm has considered both the energy correlation across the scale and also, various sub bands at the same level of the wavelet pyramid; in addition, it employed a vector HMM model. To HMM tree structure, the embedding strategy was optimized and projected. They improved the performance via the dynamical threshold schemes. The performance of the HMM based watermarking algorithm in opposition to Stir mark attacks, for the cases such as JPEG compression, adding noise, median cut and filter was drastically made good.

A multi-resolution watermarking method was depicted by Zolghadrasli and Rezazadeh [38] on the basis of the DWT for copyright protection of digital images. As watermark, a noise type Gaussian sequence is being utilized. By taking in account the features of the HVS, watermark components are added to the significant coefficients of every chosen subband so, as to embed the watermark robustly and imperceptibly. The similarities of extracted watermarks are measured using Normalized Correlation Function (NCF) and in watermark extraction procedure, the host image is of need. To extensive range of attacks, it is shown that the method is more robust. Comparison confirms the better performance of the suggested method with that of the existing methods.

3. Human Visual System

The HVS has evolved as an important approach in digital image processing. Mannos and Sakrison established the HVS model for the first time in the year 1970`s [28]. Plentiful researchers have been experimenting on the HVS [18]. The HVS is a nonlinear and spatially varying system [31]. The design specifications of HVS are simplicity, visual sensitivity and selectivity to model and enhance perceived image quality. The HVS is on the basis of psychophysical process that connects psychological phenomena (contrast and brightness etc.,) to physical phenomena (light sensitivity, spatial frequency and wavelength etc.,). Three fundamental properties of human vision are utilized in majority of HVS models of an image processing: frequency sensitivity, luminance sensitivity and masking effects. The sensitivity of human eye to different spatial frequencies is resoluted by the frequency sensitivity [7].

The aim of quality assessment or image compression is achieved by the development of copious numbers of HVS [33]. Further by employing similar visual models, it is more likely to achieve digital watermarking of images. Robustness, perceptual transparency and capacity are the three fundamental requirements of digital watermarking techniques. The functions of the HVS models included into watermarking are: Selection of visually important image components for watermark embedding and scaling of watermark elements before embedding into original data. Numerous HVS model based watermarking techniques are present in the literature [7, 24, 38].

4. Techniques used in Proposed Approach

4.1. Multiwavelet Transform

A type of signal transform called the wavelet transform is often used in image compression. An alternative new approach to wavelet transform is the multiwavelet transform. Multiwavelets are equivalent to wavelets but with few diminutive important differences. Particularly, multiwavelets have two or more scaling and wavelet functions, with those of wavelets which have an associated scaling function Φ(t) and wavelet function Ψ(t) [25]. Geronimo, Hardian, and Massopust proposed a very important multiwavelet filter called GHM. The GHM basis provides a combination of orthogonality, symmetry, and compact support that is unachievable by any other scalar wavelet basis [30]. The GHM scaling functions have the following properties such as short support, posses second order approximation, the translation of the scaling functions are orthogonal and both scaling functions and the wavelets are symmetric.

4.2. Canny Edge Detection Algorithm

Generally, the aim of edge detection is to minimize data amount considerably in an image, it perhaps conserve the structural properties to promote further image processing. John F. Canny in 1986 established the canny edge detection operator and this on the other hand uses a multi-stage algorithm to detect a wide range of edges in images. The major characteristics of Canny to be particularly noted, it can also, produce a computational theory of edge detection explaining how the technique works [4]. The canny algorithm runs in 5 separate steps:

1. *Smoothing:* Blurring of the image to remove noise.
2. *Finding Gradients:* The edges should be marked where the gradients of the image has large magnitudes.
3. *Non-Maximum Suppression:* Only local maxima should be marked as edges.
4. *Double Thresholding:* Potential edges are determined by thresholding.
5. *Edge Tracking by Hysteresis:* Final edges are determined by suppressing all edges that are not connected to a very certain (strong) edge.

4.3. Hausdorff Distance Measure

The HD is a metric between two point sets [12]. Let $A=\{a_1,...,a_m\}$ and $B=\{b_1,...,b_n\}$ represent two finite point sets. Afterwards, the HD is expressed as:

$$H(A,B) = max(h(A,B), h(B,A)) \tag{1}$$

where, $h(A,B) = \max_{a\in A} \min_{b\in B} \| a-b \|$

Thus $h(A,B)$ is termed the directed HD from set A to B with a few basic rule $\|.\|$ on the points of A and B. To image processing applications it has confirmed to practically apply a slightly different measure, the (directed) Modified Hausdorff Distance (MHD) that was initiated by Dubuisson and Jain [5]. It is termed as [15]:

$$h_{mod}(A,B) = \frac{1}{|A|}\sum_{a\in A} \min_{b\in B} \| a-b \| \tag{2}$$

The application of the HD in image processing is image matching that is basically used to find the best matched image with lower distance. The advantage of the HD is that it provides good results, even in presence of noise or occlusion. This is the major reason to take the HD in our work for matching the image with their different band.

5. The Proposed Effective Watermarking Scheme

The scheme proposed for attaining effective watermarking is described in this section. For watermark embedding, the selection of appropriate image components is made based on the maximum distance measure of the chosen sub-band. GHM Multiwavelet transform is employed to perform watermarking in the wavelet domain. A random matrix is generated by means of a key image for embedding process. The watermark extraction requires the watermarked image, key image, size of watermark image and the information about the watermark embedded sub-band. The computed correlation coefficient and generated random matrix are also, utilized in the extraction process as well. The following sub-sections elucidate the steps concerned in the watermark embedding and extraction.

5.1. Watermark Embedding

This sub-section presents the process of embedding the watermark image into the host image. The watermark image preferred in our proposed scheme is a binary image and the host image that must be dyadic ($2^n \times 2^n$) in size. The embedding process is carried out by means of GHM multiwavelet transform in wavelet domain. To begin with, the GHM multiwavelet transform is used to decompose the host image into four sub-bands as A, H, V and D. Subsequently, excluding A, the edges of the other H, V and D sub-bands are detected using canny edge detection algorithm. Followed by, the distance between each sub-band is measured with the aid of the HD and the sub-band with maximum distance value is chosen for watermark embedding. The random matrix is generated on the basis of a key image. Consequently, the selected sub-band from host image is utilized to embed the binary watermark image. The generated random matrix and the embedding strength are utilized to embed the binary watermark into the host image. Finally, the embedded sub-band with the watermark is mapped back into its original position and inverse transform is applied to attain the watermarked image. The block diagram of the watermark embedding process is shown in Figure1.

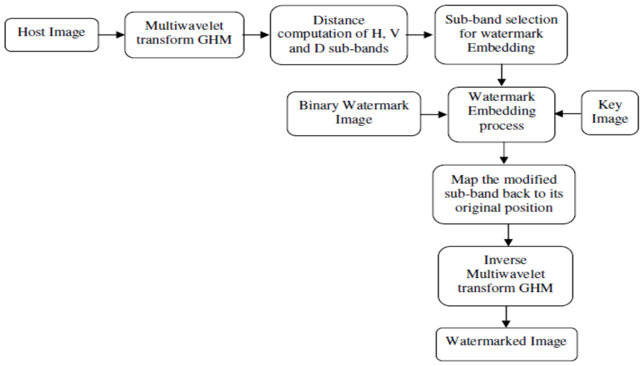


Figure 1. Watermark embedding process.

5.1.1. Steps in Watermark Embedding Process

Input: Host Image (I), Binary Watermark Image (W), Key Image (I_k).
Output: Watermarked Image (I_W).

1. Decompose the host Image I into four sub-bands (A, H, V and D) using GHM multiwavelet transform.
2. Detect the edges of all the sub-bands (excluding the A sub-band) by means of the canny edge detection algorithm.
3. Find the edge pixels in each block and subsequently, determine the distance between each sub-band using HD.
4. Select a sub-band with maximum distance measure from the three sub-bands (H, V, D) for embedding the watermark image (W) and is denoted as I_M.
5. Generation of an initial random matrix R:
   a. Summation of the pixel values in the key image (I_k). The summed values are denoted as R_{seed}.

$$R_{seed} = \sum_{i=1}^{n} \sum_{j=1}^{n} I_{k_{ij}} \quad (3)$$

   b. Form a random matrix R with selected sub-band's size as the seed value of the pseudo random matrix generator. As the image's size is $2^n \times 2^n$, the sub-band's size will be $(2^n/2 \times 2^n/2)$.

$$R = \left[R_{seed}\right]_{\left(2^n/2 \,\times\, 2^n/2\right)} \quad (4)$$

6. Generation of a final random matrix R_M using R:
   a. Subtract 0.5 from the generated random matrix R and multiply the resultant matrix by 2 to get the final resultant matrix R_t.

$$R_t = (R - 0.5) \times 2 \quad (5)$$

   b. At last, a pseudo random matrix generator with R_t matrix as seed value is used to generate the final random matrix R_M.

$$R_M = [R_t]_{\left(2^n/2 \times 2^n/2\right)} \quad (6)$$

7. The embedding process of the binary watermark image pixels into the selected sub-band is described subsequently For embedding the pixel value '0', multiply the random matrix R_M 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:

$$[I_M] = [I_M] + (\beta * [R_M]) \quad (7)$$

   where $\beta = 2$
8. The steps 6 and 7 are repeated until all the watermark pixels are embedded. For every iteration, Pseudo random matrix generator initiated with seed R_{seed} generates the initial random matrix R.
9. Map the modified sub-band (I_M) back to its original position and application of inverse multiwavelet transform to attain the watermarked image I_W.

5.2. Watermark Extraction

The extraction of watermark image from the watermarked image is explained in this sub-section. The necessary elements for the extraction of the watermark image: the watermarked image, size of watermark image, key image and the information about the sub-band in which the watermark has been embedded. Initially, a random matrix is generated from the key image as the steps discussed in the previous sub-section. Subsequently, the watermark pixels are extracted with the aid of the computed correlation coefficient and the generated random matrix. The block diagram of the watermark extraction process is portrayed in Figure 2.

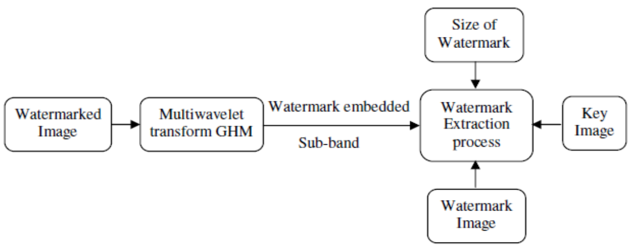


Figure 2. Watermark extraction process.

5.2.1. 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. Decompose the watermarked image (I_W) using GHM multiwavelet transform and selection of the watermark embedded sub-band (I_M) based on the sub-band information.
2. Generate the random matrix R_M by applying the steps 4 and 5 mentioned in the previous sub-section. Similarly, for every iteration the initial random matrix R is generated from the pseudo random matrix generator initiated with R_{seed}.
3. Compute the correlation coefficient (r) between the sub-band (I_M) and the generated random matrix R_M:

$$r=\frac{\sum_m\sum_n (A_{mn}-\overline{A})(B_{mn}-\overline{B})}{\sqrt{\left(\sum_m\sum_n (A_{mn}-\overline{A})^2\right)\left(\sum_m\sum_n (B_{mn}-\overline{B})^2\right)}} \quad (8)$$

where:

$A_{mn} \rightarrow$ sub-band (I_M)
$B_{mn} \rightarrow$ Random Matrix (R_M)
$\overline{A} \rightarrow$ Mean value of A
$\overline{B} \rightarrow$ Mean value of B

4. Apply the division operation on the calculated correlation coefficient value (r) with two and the resultant value is represented as R_V.

$$R_V=r/2 \quad (9)$$

5. The steps 2 to 4 are repeated for the size of watermark image and the resultant values R_V are stored in a vector VR_V.
6. Compute the mean value of the vector VR_V.

$$\overline{VR_V}=\frac{\sum_{i=1}^{k} VR_V^i}{|VR_V|} \quad (10)$$

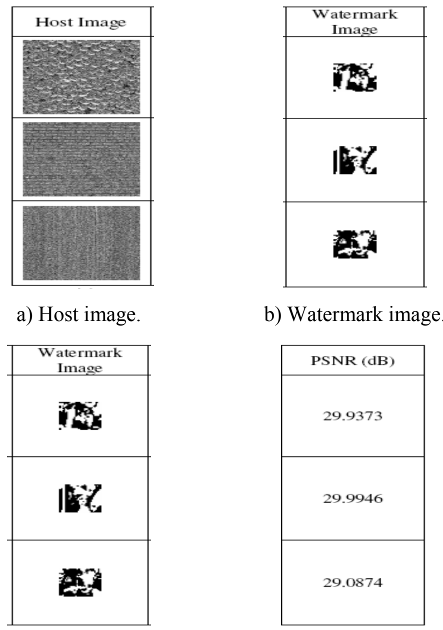
7. Comparison of the elements of the vector VR_V against the mean value $\overline{VR_V}$ for extracting the watermark image pixels. If the VR_V's element value is greater than the mean value, the extracted watermark image pixel is '0', otherwise the pixel value is '1'. The corresponding equation for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

$$W(x,y)=\begin{cases}0, & VR_V^i > \overline{VR_V}\\ 1, & Otherwise\end{cases} \quad (11)$$

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

6. Experimental Results

The experimental results and analysis of the proposed watermarking scheme is presented in this section. The proposed watermarking scheme is programmed in Matlab (Matlab 7.4). The experiments are carried out with the texture images obtained from Brodatz Texture Image database [23]. The texture images in the database are of size 640×640. An image of size 35×1 is chosen as 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. Figure 3 depicts the watermark and watermarked images of three different host images with their respective PSNR values. From the Figure 3, we can identify that the proposed method has achieved the maximum PSNR of 29.99db without applying any attacks.



a) Host image. b) Watermark image.

c) Watermarked image. d) PSNR value.

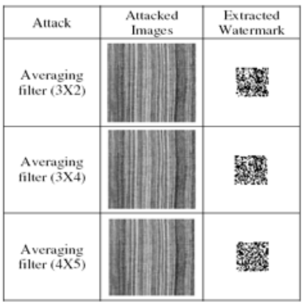
Figure 3. watermark and watermarked images of three different host images with their respective PSNR values.

To facilitate the robustness of the proposed watermarking scheme, we have performed a range of attacks on watermarked images in our experiments. Figure 4 shows the results of different image attacks such as Gaussian blur, Gaussian noise, Gaussian filter, Wiener filter, Sharpening, Cropping, Intensity value adjustment, averaging filter along with their extracted watermark images. Table 1 shows the correlation coefficients calculated between the original watermark and the extracted watermark from the attacked watermarked images. The robustness of the proposed scheme is evident from the experimental evaluation.

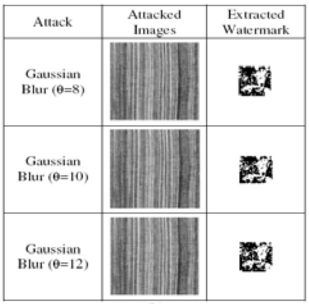
Table 1. Correlation coefficient values of the attacks.

Attacks	Correlation Coefficient		
Averaging Filter	3×2	3×4	4×5
	0.7837	0.6245	0.6196
Gaussian Blur	θ=8	θ=10	θ=12
	0.8610	0.8404	0.8196
Cropping	Upper left	Middle	Right
	0.8262	0.8567	0.8831
Intensity Adjustment	Low-0.2, high-0.4	Low-0.4, high-0.6	Low-0.4, high-0.9
	0.7962	0.6962	0.8809
Gaussian Noise	σ=25	σ=50	σ=100
	0.9848	0.9429	0.8748
Sharpening	α=0.4	α=0.7	α=0.9
	0.9318	0.8078	0.8974
Weiner Filtering	2×2	4×4	4×8
	0.8581	0.7966	0.8815

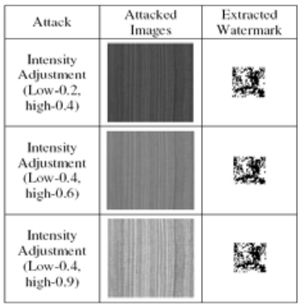
Table 1 shows the correlation coefficient of the proposed method achieved for the different attacks. Here, we have obtained the maximum correlation value of 0.88 for wiener filtering attack, which is high compared with average filtering. In noisy attacks, the maximum value of 0.98 is achieved by the proposed method in Gaussian noise. We have obtained the value of 0.9318 even if the watermarked image is applied to sharpening process. The overall results ensured that the proposed method is robust in watermarking process since the information is not much lost even if we are applying the various attacks.



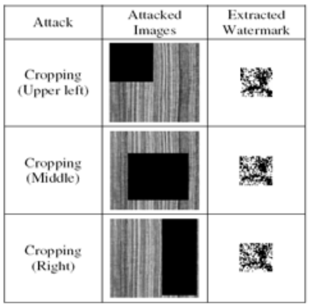
a) Average filter.



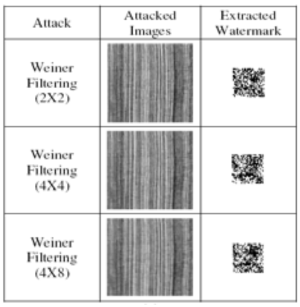
b) Gaussian blur.



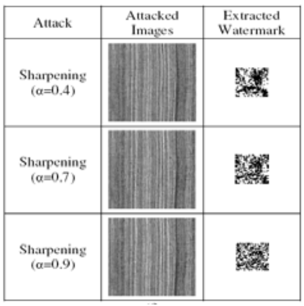
c) Cropping.



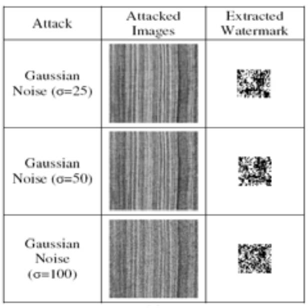
d) Intensity adjustment.



e) Gaussian noise.



f) Sharpening.



g) Wiener filter.

Figure 4. Attacked watermarked images, extracted watermark image.

7. Conclusions

The decisive requirement of copyright enforcement techniques is due to the unauthorized exploitation of digital images. This technique serves the protection of copyright ownership. In this paper, we have depicted an effective wavelet-based watermarking scheme via HVS to protect the copyrights of digital images. The watermarking has been done in wavelet domains with the support of multiwavelet transform. To attain an effective copyright protection of images, the proposed scheme has enabled the creation of an efficient watermarking by the incorporation of HVS model within it. The calculated distance measure has been used to select image components suitable for embedding. A random matrix was generated by a key image and it has been applied in the proposed watermarking scheme. The computed correlation coefficient is utilized in the extraction process. The proposed scheme has met both the following requirements for effective copyright protection scheme: imperceptibility and robustness. The experimental results have demonstrated the efficiency and robustness of the proposed scheme with the assist of attacks.

References

[1] Akhaee M., Sahraeian S., Sankur B., and Marvasti F., "Robust Scaling Based Image Watermarking using Maximum Likelihood Decoder with Optimum Strength Factor," *IEEE Transactions on Multimedia*, vol. 11, no. 5, pp. 822-833, 2008.

[2] Canny J., "A Computational Approach to Edge Detection," *IEEE Transactions Pattern Analysis and Machine Intelligence*, vol. 8, no. 6, pp. 679-698, 1986.

[3] Colle F. and Gomez J., "DWT Based Digital Watermarking Fidelity and Robustness Evaluation," *Journal of Computer Science & Technology*, vol. 8, no. 1, pp. 15-20, 2008.

[4] Deriche R., "Using Canny's Criteria to Derive a Recursively Implemented Optimal Edge Detector," *International Journal of Computer Vision*, vol. 1, no. 2, pp. 167-187, 1987.

[5] Dubuisson M. and Jain A., "A Modified Hausdorff Distance for Object Matching," *in Proceedings of the 12th IAPR International Conference on Computer Vision and Image Processing*, Jerusalem, pp. 566-568, 1994.

[6] Ellinas J. and Kenterlis P., "A Wavelet-Based Watermarking Method Exploiting the Contrast Sensitivity Function," *International Journal of Signal Processing*, vol. 3, no. 4, pp. 266-272, 2006.

[7] Foriš P. and Levický D., "Implementations of HVS Models in Digital Image Watermarking," *Journal of Radio Engineering*, vol. 16, no. 1, pp. 45-50, 2007.

[8] Hsieh S., Tsai I., Huang B., and Jian J., "Protecting Copyrights of Color Images using a Watermarking Scheme Based on Secret Sharing and Wavelet Transform," *Journal of Multimedia,* vol. 3, no. 4, pp. 42-49, 2008.

[9] Hsu C. and Tu S., "An Imperceptible Watermarking Scheme using Variation and Modular Operations," *International Journal of Hybrid Information Technology*, vol. 1, no. 4, pp. 233-237, 2008.

[10] Jehad A., "An Efficient Region-Based Approach for Object Recognition and Retrieval Based on Mathematical Morphology and Correlation Coefficient," *International Arab Journal of Information Technology*, vol. 5, no. 2, pp. 154-162, 2008.

[11] Jehad O., Ahmad H., Othman M., and Johari R., "Image Retrieval System Based on Density Slicing of Colour Histogram of Images Subareas and Colour Pair Segmentation," *International Arab Journal of Information Technology*, vol. 1, no. 2, pp. 196-202, 2004.

[12] Jesorsky O., Kirchberg K., and Frischholz R., "Robust Face Detection using the Hausdorff Distance," *in Proceedings of the 3rd International Conference on Audio and Video-based Biometric Person Authentication*, Sweden, pp. 90-95, 2001.

[13] Khaled M., Sekharjit D., and James F., "Frequency Domain Watermarking: An Overview," *International Arab Journal of Information Technology*, vol. 2, no. 1, pp. 33-47, 2005.

[14] Kim Y. and Choi B., "Two-Step Detection Algorithm in a HVS-Based Blind Watermarking of Still Images," *in Proceedings of Lecturer Notes in Computer Science*, Korea, vol. 2613, pp. 235-248, 2003.

[15] Kirchberg K., Jesorsky O., and Frischholz R., "Genetic Model Optimization for Hausdorff Distance-Based Face Localization," *in Proceedings of International ECCV Workshop on Biometric Authentication*, Denmark, pp. 103-111, 2002.

[16] Lu Z., Zheng W., Pan J., and Sun Z., "Multipurpose Image Watermarking Method Based on Mean-Removed Vector Quantization," *Journal of Information Assurance and Security*, vol. 1, no. 1, pp. 33-42, 2006.

[17] Maity S. and Kundu M., "An Image Watermarking Scheme using HVS Characteristics and Spread Transform," *in Proceedings of the 17th International Conference on Pattern Recognition*, India, vol. 4, pp. 869-872, 2004.

[18] Mannos J. and Sakrison D., "The Effect of a Visual Criterion in the Encoding of Images," *IEEE Transaction on Information Theory*, vol. 20, no. 4, pp. 525-536, 1974.

[19] Mohanty S., Kougianos E., and Ranganathan N., "VLSI Architecture and Chip for Combined Invisible Robust and Fragile Watermarking," *Computers & Digital Techniques*, vol. 1, no. 5, pp. 600-611, 2007.

[20] Nasser H., "Hiding Text Information in a Digital Image Based on Entropy Function," *International Arab Journal of Information Technology*, vol. 7, no. 2, pp. 146-151, 2010.

[21] Padmanabhareddy V. and Varadarajan S., "Human Visual System Sentient Imperceptible and Efficient Wavelet-Based Watermarking Scheme for Copyright Protection of Digital Images," *International Journal of Computer Science and Network Security*, vol. 9, no. 4, pp. 255-264, 2009.

[22] Padmanabhareddy V. and Varadarajan S., "An Effective Wavelet-Based Watermarking Scheme using Human Visual System for Protecting Copyrights of Digital Images," *International Journal of Computer and Electrical Engineering*, vol. 2, no. 1, pp. 32-39, 2010.

[23] Picard R., Kabir T., and Liu F., "Real-Time Recognition with the Entire Brodatz Texture Database," *in Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, USA, pp. 638-639, 1993.

[24] Qi X., "An Efficient Wavelet-Based Watermarking Algorithm," *in Proceedings of Hawaii International Conference on Computer Sciences*, Hawaii, pp. 383-388, 2004.

[25] Radhakrishnan S. and Subramaniam J., "Novel Image Compression using Multiwavelets with SPECK Algorithm," *International Arab Journal of Information Technology*, vol. 5, no. 1, pp. 45-51, 2008.

[26] Rezazadeh S. and Yazdi M., "A Non-Oblivious Image Watermarking System Based on Singular Value Decomposition and Texture Segmentation," International Journal of Applied Science, Engineering and Technology, vol. 1, no. 3, pp. 142-146, 2006.

[27] Sakr N., Georganas N., and Zhao J., "Copyright Protection of Image Learning Objects using Wavelet-Based Watermarking and Fuzzy Logic," *in Proceedings of Intelligent Interactive Learning Object Repositories Conference*, Canada, pp. 1-7, 2006.

[28] Sullivan J., Ray L., Miller R., "Design of Minimum Visual Modulation Halftone Patterns," *IEEE Transactions on Systems, Man and Cybernetics*, vol. 21, no. 1, pp. 33-38, 1991.

[29] Tian J., "Wavelet-Based Reversible Watermarking for Authentication," *in Proceedings of Security and Watermarking of Multimedia Contents IV*, San Jose, vol. 4675, pp. 679-690, 2002.

[30] Tombras G., Salih S., and Mansour A., "Performance Study of MC-CDMA Based on Multiwavelet Transform," *MASAUM Journal of Basic and Applied Sciences*, vol. 1, no. 1, pp. 271-274, 2009.

[31] Veeraswamy K., Srinivaskumar S., and Chatterji B., "Designing Quantization Table for Hadamard Transform Based on Human Visual System for Image Compression," *International Journal on Graphics, Vision and Image Processing*, vol. 7, no. 3, pp. 31-38, 2007.

[32] Vleeschouwer C., Delaigle J., and Macq B., "Invisibility and Application Functionalities in Perceptual Watermarking an Overview," *in Proceedings of IEEE*, vol. 90, no. 1, pp. 64-77, 2002.

[33] Vleeschouwer C., Delaigle J., and Macq B., "Invisibility and Application Functionalities in Perceptual Watermarking an Overview," *in Proceedings of IEEE*, vol. 90, no. 1, pp. 64-77, 2002.

[34] Wolfgang R., Podilchuk C., and Delp E., "Perceptual Watermarks for Image and Video," *in Proceedings of IEEE*, USA, vol. 87, no. 7, pp. 1108-1126, 1998.

[35] Yue Z., Qun N., and Wu H., "An Adaptive Image Watermarking Algorithm Based on HMM in Wavelet Domain," *Acta Automatica Sinica*, vol. 31, no. 5, pp. 705-712, 2005.

[36] Zaboli S., Tabibiazar A., and Safabakhsh R., "Entropy-Based Image Watermarking using DWT and HVS," *in Proceedings of the 3rd International Conference: Sciences of Electronic, Technologies of Information and Telecommunications*, Tunisia, pp. 1-6, 2005.

[37] Zhang X., Feng J., and Lo K., "Image Watermarking using Tree-Based Spatial-Frequency Feature of Wavelet Transform," *Journal of Visual Communication and Image Representation*, vol. 14, no. 4, pp. 474-491, 2003.

[38] Zolghadrashli A. and Rezazadesh S., "Evaluation of Spread Spectrum Watermarking Schemes in the Wavelet Domain using HVS Characteristics," *in Proceedings of the 9th International Symposium on Signal Processing and its Applications*, Sharjah, vol. 5, pp. 1-4, 2007.

Padmanabhareddy Vundela received his B.Tech in electronics and communication engineering from Regional Engineering College, Warangal, India and M.Tech in digital systems and computer electronics from J.N.T. University College of Engineering, India. He is working towards his PhD, at Sri Venkateswara University College of Engineering, India. He has eleven years experience of teaching under graduate students and post graduate students. Currently, he is working at the Department of Information Technology, Vardhaman College of Engineering, India. His research interest includes digital image processing and digital image watermarking.

Varadarajan Sourirajan received his B.Tech degree in electronics and communication engineering from Sri Venkateswara University in 1987 and M.Tech degree from NIT. He did his PhD in the area of radar signal processing. He is fellow of Institute of Electronics and Telecommunication Engineers and member of IEEE. Currently, he is working as an associate professor in the Department of IEEE, Sri Venkateswara University, India.