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A Novel Robust Blind Watermarking for Color Images in the Wavelet Domain Achieving High Reversibility

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Abstract- Watermarking is a technique to protect the copyright of digital media such as image, text, music and movie. Reversible watermarking methods are used for copyright protection and able to recover the host image without distortion. Robust reversible watermarking technique should resist against intentional and unintentional image processing attacks. In this paper, a novel robust reversible blind watermarking scheme for color images is proposed. In the proposed approach, the red component of a host color image is decomposed into wavelet coefficients. Watermark is embedded in HH sub-band for achieving high imperceptibility. In order to achieve robustness, and to achieve a balance between imperceptibility and robustness, embedding strength is determined by pixel-wise masking concept and also watermark bits are inserted in the HH sub-band as rising and falling edges. Watermark extraction technique is a blind technique and host image is not required for extracting watermark.

Keywords – Watermarking, Reversibility, Copyright Protection, Wavelet, Blind Watermarking, Color Images.

1. INTRODUCTION

The advance of computer technologies and the proliferation of the internet have made reproduction and distribution of digital information easier than ever before. Copyright protection of intellectual properties has, therefore, become an important topic. One way for copyright protection is digital watermarking[1]-[7], which means embedding of certain specific information about the copyright holder (company logos, ownership descriptions, etc.) into the media to be protected.

Digital watermarking methods for images are usually categorized into two types: invisible and visible. Invisible type aims to embed copyright information imperceptibly into host media such that in cases of copyright infringements, the hidden information can be retrieved to identify the ownership of the protected host. It is important for the watermarked image to be resistant to common image operations to ensure that the hidden information is still retrievable after such alterations.

Methods of visible watermarking type on the other hand, yield visible watermarks which are generally clearly visible after common operations are applied. In addition, visible watermarks convey ownership information directly on the media and can deter attempts of copyright violations.

There are two broad categories of digital image watermarks, depending on where the watermark is created and embedded, namely spatial and spectral watermarks. Spatial Watermarks are created in the spatial domain of the image, and are embedded directly into the pixels of the image. Spectral (or transform-based) watermarks are incorporated into the image's transform coefficients. That is, the transform coefficients of the image are used in creating and embedding the watermark. The associated watermarking techniques are called frequency domain techniques. Examples of transforms that are used are the Discrete Cosine Transform (DCT), the Wavelet Transform, and the Fast Fourier Transform, which transform the image into the frequency domain. However, DWT has been used in digital image watermarking more frequently due to its excellent spatial localization and multi-resolution characteristics, which bare similar to the theoretical models of the human visual system.

Another way of classification is blind and non-blind watermarking systems. In non-blind watermarking systems, the detector requires either the original image or some information about the original image. However, in blind watermarking systems, there is no need of original or any information about the original image.

2. PRELIMINARIES

2.1 Watermarking

Watermarking is a technique to protect the copyright of digital media such as image, text, music and movie. A watermarking scheme combines cover images with a watermark which is hard to be detected and removed, and the owner of the image can prove his copyright by extracting the watermark. Watermarking schemes for digital images suffer a lot of attacks that aim at severing the relationship between the watermarked image and the watermark, such as compression attack, blurring attack, sharpening attack, scaling attack, cropping attack, distortion attack and noise attack. Generally, a watermarking scheme should possess the following features:

1. *Imperceptibility*: It is hard to detect the differences between the original cover images and the watermarked ones by the human visual system. The imperceptibility is perfect if the watermarked images are identical/indistinguishable to the original cover images.
2. *Robustness:* The watermark still can be extracted even if the watermarked image suffers from various attacks.
3. *Security:* Only the owner of the cover images can extract the watermark from the watermarked image.
4. *Blindness:* The original cover images are not required for extracting the watermark. Hence, extra space is not required for storing the cover images.

2.2 Reversibility

Embedding of watermarks, either visible or invisible, degrade the quality of the host media in general. *Reversible* watermarking, allow legitimate users to remove the embedded watermark and restore the original content as needed. Also reversible watermarking preserves high intactness and good fidelity of host media. Host image recovery is important in many applications where serious concerns about image quality arise. Some examples include forensics, medical image analysis, historical art imaging, or military applications. The RRW is thus a challenging task. For RRW, the essential objective is to accomplish watermark embedding and extraction in both lossless and lossy environment. As a result, RRW is required to not only recover host images and watermarks without distortion for the lossless channel, but also resist unintentional attacks and extract watermarks.

2.3 Discrete Wavelet Transform Technique

Currently, most of the watermarking schemes are based on the transform domain techniques, including the Discrete Fourier Transform, the Discrete Cosine Transform and the Discrete Wavelet Transform (DWT), because they provide better performance with respect to the robustness than that based on the spatial domain. DWT offers multi-resolution representation of image and gives perfect reconstruction of decomposed image. Discrete wavelet $\Psi_{j,k}(t)$ can be represented as

$$\Psi_{j,k}(t) = a_0^{-\frac{i}{2}}\Psi(a_0^{-j}t - kb_0) \qquad (1)$$

For dyadic wavelets a_0 =2 and b_0 =1, Hence we have,

$$\Psi_{j,k}(t)=2^{-j/2}\psi(2^{-j}t-k) \qquad j,k\epsilon Z \qquad (2)$$

When an image is passed through a series of low pass and high pass filters, DWT decomposes the image into several sub-bands in three different directions: horizontal, vertical and diagonal. It decomposes an image into low and high frequencies using respectively low-pass and high-pass filters. The result is an approximation image having a halved resolution normally labeled as LL sub-band and three detail images (LL, HL and HH) which give the errors between the original image and the approximation image. The low frequencies are concentrated on the top left corner of the transform (LL) and look like a compressed version of the original image. Despite the complexity of the computation of the wavelet coefficients, the DWT is much closer to the human visual system than that of DCT or DFT.

In general most of the image energy is concentrated at the lower frequency sub-band LL and therefore embedding watermarks in this sub-band may degrade the image significantly. On the other hand, the high frequency sub-band HH, includes the edges and textures of the image and the human eye is not generally sensitive to changes in such sub-bands. This allows the watermark to be embedded without being perceived by the human eye. Hence HH sub-band is chosen for watermark embedding. Here Haar filter is used. Fig.1 shows the single level wavelet decomposition.

LL	HL
LH	HH

Fig.1 Single Level Wavelet Decomposition

Watermarking schemes based on the transform domain technique often have better robustness. The transform domain technique can extract the feature image of the cover image; hence, watermarking schemes based on the transform domain technique often have strong robustness against compression attacks such as JPEG compression.

2.4 Pixel-Wise Masking (PWM)

To effectively balance robustness and invisibility, we consider the local sensitivity of human visual system (HVS) in wavelet domain, and design an PWM to precisely evaluate the Just Noticeable Distortion (JND) thresholds of wavelet coefficients, which thereafter are used to adaptively optimize watermark strength.

A balance between invisibility and robustness is important for robust watermarking methods. Therefore, we develop PWM to tackle this problem by utilizing the JND thresholds of wavelet coefficients to optimize watermark strength. PWM focuses on improving the local sensitivity of images to noise by mainly estimating brightness and texture sensitivities in a more precise way.

The JND is determined by taking into account, brightness sensitivity, texture sensitivity and the difference between resolution levels. We use the obtained JND thresholds to control watermark strength during the embedding process.

For obtaining robustness a trade-off between invisibility and robustness must be achieved. Hence determining watermark strength (λ) is important. Watermark strength is determined in such a way that both invisibility and robustness should be achieved. Watermark strength is achieved by the following procedure.

2.5 Edge Insertion

Edges in digital images are areas with strong intensity contrasts and a jump in intensity from one pixel to the next can create major variation in the picture quality. With the help of first- and second- order derivatives such discontinuities are detected. The first-order derivative of choice in image processing is the gradient. An image gradient is a directional change in the intensity or color in an image. Image gradients may be used to extract information from images. Proposed technique inserts watermark bits in HH sub-band as rising and falling edges. Bits are represented as NxN blocks. NxN blocks chosen here are 8x8 blocks. For inserting watermark bit 1, the mask used is shown in Fig. 2.(a) and for inserting watermark bit 0, the mask used is shown in Fig.2 (b).

1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1
1	1	1	1	-1	-1	-1	-1

(a)

-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1
-1	-1	-1	-1	1	1	1	1

(b)

Fig.2 (a) Block representing 1 (b) Block representing '0'

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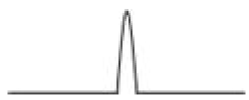
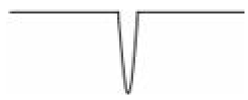
The above two blocks are modeled as edges : the first is a rising edge E_r and the second is a falling edge E_f. Therefore, their gradient along the horizontal axis is a peak for (a) and a hollow for (b). The gradients are obtained by differentiating the two blocks as shown in Fig.3.



(a)



(b)

Fig. 3 Gradients of a (a) Rising Edge (b) Falling Edge

If watermark bit is 1, the technique inserts rising edge in the image. If watermark bit is zero, the technique inserts falling edge in the image. The extraction of the watermark detects the presence of these edges in the image. This technique does not require host image for watermark extraction and hence the proposed technique is a blind watermarking technique.

3. PROPOSED TECHNIQUE

The proposed scheme is a 'A Novel Robust Reversible Blind Watermarking for Color Images in the Wavelet Domain using HH Sub-band and Edge Insertion'. The proposed watermarking scheme contains two algorithms namely the embedding algorithm and the extraction algorithm. In the embedding algorithm, the owners generate watermarked image, by embedding watermark invisibly into the host image. They publish the watermarked images after registering with the arbitrator. After the watermarked images are published, the attackers may modify and use them illegally. The attacks may be unintentional attacks or intentional attacks. In such a case, the legal owners need to show their evidences (their watermarks) to claim their copyright of the watermarked images. In the extraction algorithm, an extracted watermark can be extracted from the attacked image also. By comparing the extracted watermark and the original watermark, the arbitrator can judge whether they own the copyright of the attacked images or not.

Inserting watermark bits in HH sub-band is not robust. But imperceptibility is high. In order to increase robustness, and to achieve a balance between invisibility and robustness, embedding strength λ is determined by PWM concept and also watermark bits are inserted in the HH sub-band as rising and falling edges. Red component is chosen for embedding watermark. Watermark extraction technique is a blind technique and host image is not needed for extracting watermark.

Algorithm 1: Embedding Algorithm.

Initially the Red component (R) of the given image is extracted from the host image (I) and one level wavelet decomposition is applied resulting in LL, HH, HL and LH sub-bands.

The embedding process involves two processes namely a) Watermark Strength Determination and b) Watermarking.

a) Watermark Strength Determination:

Watermark strength is computed using the following procedure.

- Calculate the luminance masking of the low-pass sub-band at resolution level ρ .

$$LM(\rho,i,j)=1+\begin{cases}1-\Delta(\rho,i,j), if\ \Delta(\rho,i,j)<0.5\\ \Delta(\rho,i,j), \quad otherwise\end{cases} \quad (3)$$

$$\Delta(\rho,i,j)=\frac{1}{256}a_3^{LL}\left(1+\left\lfloor\frac{i}{2^{3-\rho}}\right\rfloor,1+\left\lfloor\frac{j}{2^{3-\rho}}\right\rfloor\right) \quad (4)$$

where a_3^{LL} is the low-pass sub-band at the forth resolution level.

- Evaluate the texture sensitivity at the resolution level ρ by considering LH, HL and HH sub-bands.

$$TS^{\omega}(\rho,i,j)=\sum_{k=0}^{3-\rho}\frac{1}{16^k}\sum_{\omega}\sum_x\sum_y\left[a_{k+\rho}^{\omega}\left(x+\frac{i}{2^k},y+\frac{j}{2^k}\right)\right]^2$$

$$\text{x } Var\left\{a_3^{LL}\left(1+x+\frac{i}{2^{3-\rho}},1+y+\frac{j}{2^{3-\rho}}\right)\right\} \; x=0,1 \; y=0,1. \quad \omega\epsilon\{LH,HL,HH\} \quad (5)$$

- Determine the resolution (RS) with orientation $\omega \in \{LL,LH,HL,HH\}$ as follows:

$$RS(\omega)=\begin{cases}\sqrt{2},\ if\ \ \omega=HH\\ 1,\ otherwise\end{cases} \quad (6)$$

- Obtain the Just Noticeable Difference (JND) as the product of luminance masking, texture sensitivity and resolution level.

$$JND_{\rho}^{\omega}(i,j)=RS(\omega)*LM(\rho,i,j)*[TS^{\omega}(\rho,i,j)]^{0.02} \quad (7)$$

- Now, determine embedding strength (λ) as

$$\lambda=\frac{\alpha}{M\times N}\sum_{i=1}^{M}\sum_{j=1}^{N}JND_{\rho}^{\omega}(i,j) \quad (8)$$

Where α is a global parameter, ρ is the level of the decomposition and M x N is the sub-band size. In our case, ρ=1.

b) Watermarking:

- Divide HH Sub-band into 8x8 non-overlapping blocks B_i where *i* is the sub-block index .
- Form the masks for inserting watermark bits 0s(Falling Edge E_f) and 1s (Rising Edge E_r) as shown in fig.2(a) and (b).
- Embed watermark bits in B_i using the following procedure.

  If watermark bit (w = 1) then

  $B_i^w = B_i + \lambda E_r$ (9)

  Otherwise set

  $B_i^w = B_i + \lambda E_f$ (10)

- Apply IDWT to the resultant watermark embedded matrix to form R^w.
- Combine R^wGB components to form watermarked colour image I^w.

The design of the embedding technique is shown in Fig. 4.

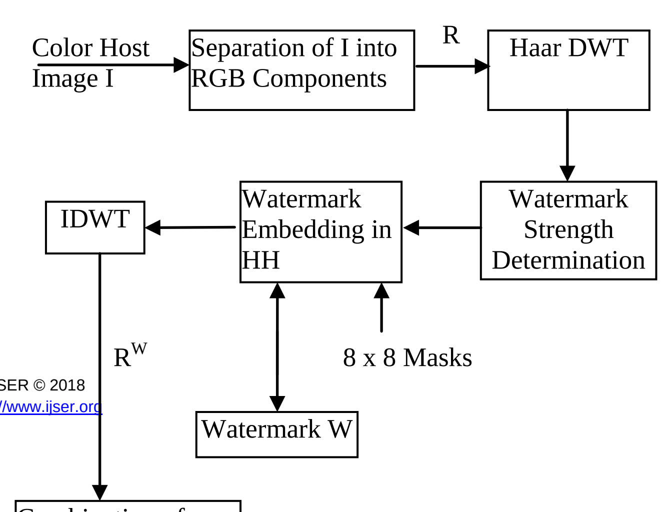


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Fig.4 Embedding Technique

According to the embedding algorithm, the watermarked images are identical to the cover images. Hence, the imperceptibility of our scheme is perfect.

Algorithm 2: Extraction Algorithm.

The steps are given below.

1. Read watermarked image I^w and watermark strength λ.
2. Separate I^w into R^wGB components.
3. Perform one level DWT of R^w to decompose into four sub-bands named as LL', LH', HL' and HH'.
4. Divide HH' Sub-band into 8x8 non-overlapping blocks B_i^w.
5. Compute the respective gradient coefficients block G_i of each B_i^w block.
6. Extract the watermark by the following procedure.
   For each G_i do the following.
   Determine GSumi $= \sum_{m=1}^{8} \sum_{n=1}^{8} G_i\,(m,n)$
   If $(GSum_i > 0)$ then set watermark bit $w^e = 1$
   Otherwise set watermark bit $w^e = 0$
7. Do the following in HH' for host image recovery.
8. For each B_i^w in HH', do the following.
   If $(w^e = 1)$ then set $B_i^r = B_i^w - \lambda E^r$ (11)
   Otherwise set $B_i^r = B_i^w - \lambda E^f$ (12)
9. Combine the sub-blocks B_i^r two dimensionally to form HH^r.
10. Perform Inverse DWT using LL', LH', HL' and HH^r to obtain recovered red component R^r.
11. Combine R^rGB components to obtain the recovered color image I^r.
12. Output the Extracted watermark W^E and recovered image I^r.

The design of the Extraction Algorithm is shown in Fig.5 .

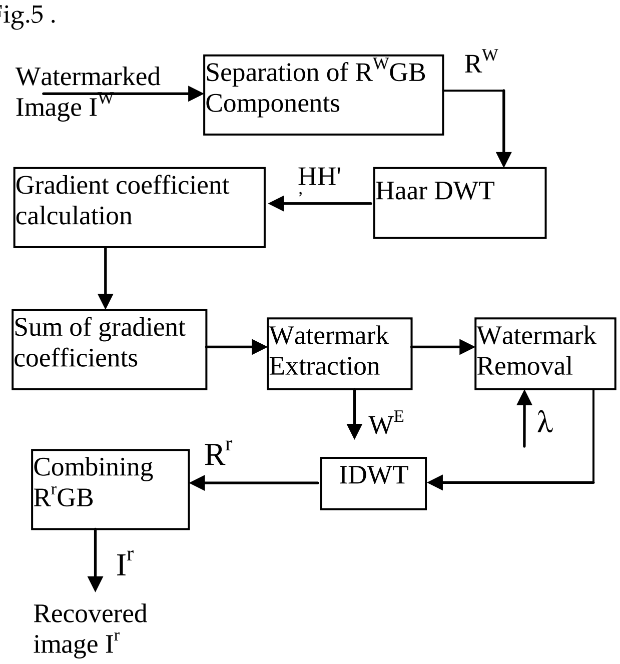

Fig.5 Extraction Technique

In the Extraction Algorithm, the extraction of the watermark does not require the original cover image, that is, it satisfies the blindness property. The robustness of the proposed scheme will be demonstrated in Section 4 by simulations against various attacks.

4. SIMULATIONS

We have used the Matlab 2010a to perform the simulations. The test images are shown in Fig.6, where (a) is the cover image with size 512 x 512, and (b) is the watermark with size 32 x 32.

(a) Cover Image (Lena) (b) Watermark

Fig.6 Test Images

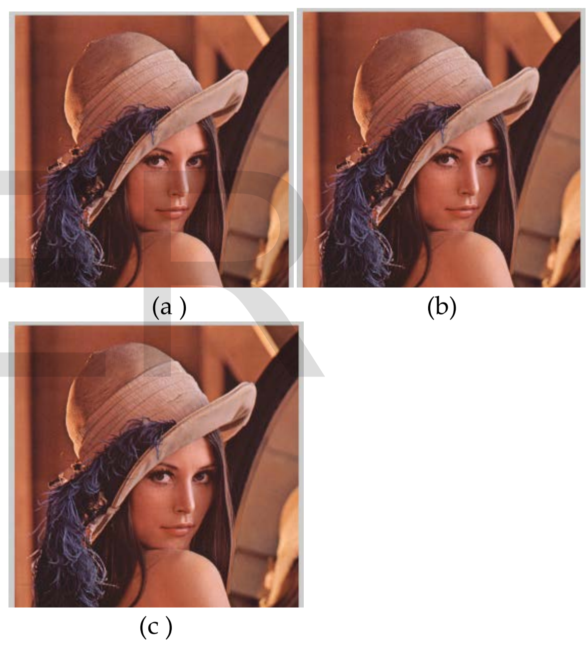

Fig.7 Watermarked and Recovered Images (a) Cover Image (b) Watermarked Image and (c) Recovered Image

Fig.7 shows the original, watermarked and recovered images of cover images. We make use of the peak signal-to-noise ratio (PSNR) to measure the differences between the original image and the watermarked image and also original image and recovered image. Smaller PSNR indicates more differences between the original image and the watermarked image or recovered image. Two identical images will result in an infinite PSNR. Usually, the attacked image can be viewed as the original image that suffers an image quality loss, and the loss of image quality is considered to be acceptable if the PSNR is above 20 dB [18]. Typically, PSNR is defined as follows.

$$PSNR = 10\,\log_{10}\frac{255^2}{MSE}\,db \qquad (13)$$

Here, 255 represents the maximum value of each pixel and the Mean Square Error (MSE) for an image is defined as

$$MSE = \left(\frac{1}{M * N}\right)\sum_{i}^{M}\sum_{j}^{N}\left(x_{ij} - x_{ij}^{'}\right)^{2} \quad (14)$$

Here, notations M and N represent the height and width of an image, respectively, x_{ij} is the pixel value of the coordinate (x, y) of an original image and x_{ij}' is the pixel value after hiding processing or after recovery. Watermark is embedded in the red component of the host image. We tested watermark embedding in LL, HL, LH and HH sub-bands. By using LL and HL sub-bands for watermark embedding, imperceptibility is not achieved and hence these two sub-bands are not chosen. Compared to LH sub-band, implementation in the HH sub-band gives better quality of the recovered image and good normalized correlation for the extracted watermark as shown in Table I. By analyzing all the sub-bands, as in Table I, we finally conclude that HH is very much suitable for watermark embedding in terms of host image recovery and NC of the extracted watermark and hence we choose HH sub-band for watermark embedding. It is very difficult to extract the watermark using blind technique as host image is not used for extraction. Even then by our technique, we are able to extract the watermark successfully with NC=1 as shown in Table II.

TABLE I

Analysis of various sub-bands for Reversible Watermarking (Lena)

Sub-bands	PSNR of Watermarked Image	PSNR of Recovered Image	NC of Extracted Watermark
LL	29.2649	25.9914	0.5414
HL	29.2619	49.0496	0.9971
LH	29.2635	43.9487	0.9915
HH	29.4142	Inf	1

TABLE II

NC of Extracted Watermarks of Various Images

Image	NC Value
Lena	1
Puppy	0.9914
Birds	1
Pink Flower	1
National Image (Lotus)	1
Texture Image	1

From Table III and Fig.8 , we choose watermark strength λ as 30 since we find that this value balances between imperceptibility, reversibility and robustness. Table IV shows the PSNR values obtained for various watermarked and recovered images. From the table, it is apparent that the recovered image is identical to the original image and satisfies reversibility.

TABLE III

Analysis of Watermark Strength

Watermark Strength (λ)	PSNR of Watermarked Image	PSNR of Recovered Image	NC of Extracted Watermark	NC after JPEG Attack
10	37.7547	53.4626	0.9914	0.1380
20	32.6028	Inf	1	0.3864
25	30.7816	Inf	1	0.8144
30	29.4142	Inf	1	0.8292
40	26.8296	Inf	1	0.8056

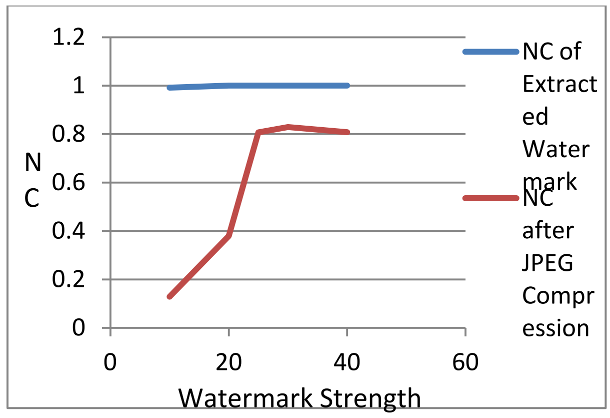

Fig.8 Graph showing impact of watermark strength (λ)

TABLE IV

PSNR Values of Watermarked Images and Recovered Images

Image	PSNR value of the Watermarked Image (dB)	PSNR value of the Recovered Image (dB)
Lena	29.2629	Inf
Puppy	28.0062	44.2369
Bird	27.1012	Inf
Pink Flower	29.2221	Inf
National Image (Lotus)	25.3470	Inf
Texture Image	29.4142	Inf

We simulate nine simple attacks on the watermarked images. These attacks are quite common in the internet environment. The simulations of these attacks and the extracted watermarks from these attacked images are shown in Fig. 9, and the NC values of extracted watermarks from the attacked images are tabulated in Table V. In Fig.9, 9(a) is the noisy image that is generated by adding the salt and pepper noise with variance = 0.1; 9(b) is the noise attacked image that is generated by adding the salt and pepper noise with variance = 0.01; 9(c) is the noise attacked image that is generated by adding the Gaussian noise with variance = 0.01; 9(d) is the noise attacked image that is generated by adding the Gaussian noise with variance = 0.05; 9(e) is the brightened image; 9(f) is the JPEG compression attacked image with 80% quality; 9(g) is the JPEG compression-attacked image with 70% quality; 9(h) is the blurring attacked image that is generated by using an averaging filter with parameter 11 on the cover image; 9(i) is the sharpening-attacked image that is generated by using a multi-dimensional filter as shown below.

H= [1 2 1; 0 0 0; -1 -2 -1]

According to Fig. 9 and Table V, the proposed scheme has strong robustness against attacks described in figures shown in Fig. 9(a) – 9(i) except for the blurring.


(a)Noisy Attack(Salt&Pepper Var=0.01)


(b)Noisy Attack(Salt&Pepper Var=0.1)


(c) Noisy Attack (Gaussian Var=0.01)


(d) Noisy Attack (Gaussian Var=0.05)


(e) Brightness


(f) JPEG Compression Attack (80%)


(g) JPEG Compression Attack (70%)


(h) Blurring Attack (Average Filter)


(i) Sharpening Attack (Sobel)

Fig.9 Attacked Images and their Extracted Watermarks

TABLE V
Values of NC after Different Attacks (Lena)

Different Attacks	Normalized Correlation (NC)
Noisy Attack (Salt&Pepper Noise with Variance =0.1)	0.7235
Noisy Attack (Salt&Pepper Noise with Variance =0.01)	0.9914
Noisy Attack (Gaussian Noise with Variance =0.01)	0.9533
Noisy Attack (Gaussian Noise with Variance =0.05)	0.5266
Increasing Brightness	0.8624
JPEG Compression Attack (80% Quality)	0.8292
JPEG Compression Attack (70% Quality)	0.6253
Blurring Attack (Average Filter)	0.4247
Sharpening Attack (Sobel)	0.9773

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TABLE VI

Performance Comparison of the Proposed Method with Existing Method

Image	Existing Method [21]			Proposed Method		
	PSNR Watermarked Image (dB)	PSNR Recovered Image (dB)	NC of the Extracted Watermark	PSNR Watermarked Image (dB)	PSNR Recovered Image (dB)	NC of the Extracted Watermark
Lena	38.6747	48.9200	1	29.2629	Inf	1
Puppy	28.7331	48.8191	0.9887	28.0062	44.2369	0.9914
Bird	26.1177	48.7769	0.9971	27.1012	Inf	1
Yellow Flower	37.6860	48.9315	0.9914	29.2221	Inf	1
National Image (Lotus)	22.6920	48.4659	0.9695	25.3470	Inf	1
Texture Image	48.8052	48.7401	1	29.4142	Inf	1

Table VI shows the performance comparison of the proposed method with the existing method [21]. Although PSNR of watermarked image of the proposed method is slightly less than the existing method, the proposed method achieves better and higher reversibility in comparison with other methods during watermark embedding. Also NC of the extracted watermark after various attacks gives better value compared to previous methods.

5. CONCLUSION

In this paper, we proposed robust reversible blind watermarking scheme, which has strong robustness, imperceptibility, and satisfies the blindness and reversibility properties. Watermark is embedded in HH sub-band for achieving high imperceptibility. In order to achieve robustness, and to achieve a balance between imperceptibility and robustness, embedding strength is determined by pixel-wise masking concept and also watermark bits are inserted in the HH sub-band as rising and falling edges. Reversibility is high compared to previous methods. Watermark extraction technique is a blind technique and host image is not required for extracting watermark. We made some simulations on the robustness, and showed that our technique resists to several types of attacks.

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