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DWT based color image watermarking using maximum entropy

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Abstract
Digital watermarking techniques can be used to solve the authenticity and copyright protection issue of images. In this work, the authors have proposed an adaptive color image watermarking scheme based on DWT by combining alpha blending and entropy concept. Entropy is one of the important features of images and can be used for watermark insertion. There are two domains in which watermarking can be carried out i.e. spatial and transform domain. Here, watermark embedding is carried out in the of Y component of YC_bC_r color space. This paper also lays down the proper justification for the selection of the Y component to embed the watermark. The performance of the proposed scheme is tested over seven different standard color images. The average PSNR and SSIM of the proposed scheme are 51.6145 dB and 0.9992 respectively. Whereas, NCC of the proposed scheme under no attack condition is 1. Further, the performance of the proposed scheme is compared with other state-of-the-art techniques.

Keywords Entropy · DWT · YC_bC_r color space · Imperceptibility · Robustness

1 Introduction

Digitization of information delivers a significant advantage in saving storage space as well as easy transmission of information over the internet. Although, it gives rise to some serious problems, such as content alteration copyright violation, and authentication problems [1, 5, 14, 37]. Because of this fact, watermarking has emerged as a burning research area among the researcher. Watermarking techniques are applied in numerous fields in order to safeguard unauthorized access to content, maintain the integrity of data and its authenticity, proof of copyright, and ownership of multimedia [14, 19, 21, 40]. The digital watermarking system is composed of an embedder and a detector [13]. Here the host signal, watermark,

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and the secret key are the input for embedder and the watermarked signal/image is its output. The detector is accountable for discovering the existence of a watermark and decoding it. There are two broad categories of watermarking in the embedding domain:-Spatial & Frequency [12, 14, 29]. Now a day's frequency domain is mainly used because of it gives better robustness against various attacks [36]. Many effective watermarking methods have been advanced for the grayscale images, but for the color images, lots of work is needed and is the open research area [20]. It is because, selection of color space is crucial for various image processing applications [20, 23].

Some of the important watermarking features are robustness, imperceptibility, cost of computation, and security. The watermark's robustness and the imperceptibility of the cover object depend on the various factor. They are i) algorithm been used in the embedding and extraction process, ii) nature/ type of watermark used, and iii) the embedding strength of watermark. Selection of correct scaling factor for embedding watermark in the cover image is very crucial [4, 5, 8, 14, 34, 42]. In DWT based techniques, the original image is decomposed into four bands i.e. (LL, HL, LH and HH sub-bands) [22, 23, 31]. Due to multi-resolution functionality of DWT, watermark can be inserted into any of the four sub-bands. But high imperceptibility is provided by a watermark embedded in the high-frequency band. On the contrary, the watermark embedded in the LL band is robust against attacks [26]. Watermark embedding in the low-frequency component of the cover image results in the artifact in the watermarked image. This is because of the major variation in the high energy region. Whereas, the high-frequency band is a better choice for watermarking because in high-frequency watermark can survive noise addition and intensity change [11, 23].

Over the past few years, watermarking techniques have emerged as a reliable approach for data authentication and copyright protection [2, 12, 38]. In the development of the watermarking scheme, there has been always a trade-off between robustness and imperceptibility [14, 32]. Based on existing literature, it is safe to conclude that there is no such watermarking scheme that can safeguard against all kinds of image processing attacks as well as satisfy the property of imperceptibility simultaneously. For the researchers, to satisfy the trade-offs between the various watermarking features is the major challenge [14]. Alpha blending techniques can be used to address these trade-off [7]. The advantages of using alpha blending techniques in watermarking are [6]:

i) Insertion and extraction of the watermark turns into less complicated.
ii) It offers high security.
iii) Watermarked image is resistant against numerous attacks.
iv) It can be utilized to add invisible watermarks to the salient features of the cover image.

1.1 Motivation and contribution

Over the past few years, watermarking techniques have emerged as a reliable approach for data authentication and copyright protection. Many effective watermarking schemes have been proposed for the grayscale images, but for the color images, lots of work is needed and is the open research area. In the development of the watermarking scheme, there has been always a trade-off between robustness and imperceptibility. Also, robustness against all attacks is challenging issues for the researcher. The above discussion is the main motivation behind this proposed watermarking method. Literature studies revels that there is always a trade-off in the features of watermarking for the development of the watermarking scheme. In this proposed scheme author has proposed an adaptive watermarking scheme to address these trade-offs between the features of watermarking.

The main contribution of this study are:

i) In this work we have proposed an adaptive color image watermarking scheme in DWT domain using the alpha blending scheme. Alpha blending scheme is used to satisfy the trade-offs between imperceptibility and robustness of the watermarking scheme.
ii) The block is selected adaptively for watermark embedding using the highest entropy value.
iii) In this work, with the experimental results we had given the justification for selection of Y component of YC_bC_r color space for watermark embedding.
iv) The proposed scheme is computational efficient that the other state-of-the-art schemes. The time complexity of the proposed DWT based watermarking scheme is O(M^2). The proposed scheme gives higher watermark invisibility. Experimental, results shows that robustness of the proposed scheme is better that the other state-of-the-art.

The outline of the rest of the paper is given below. Some of the related works are discussed in Section 2. In Section 3 some preliminaries are discussed. In Section 4 color image watermarking scheme is briefly discussed and also proper justification has been given for the color space selection. Section 5 presents the proposed watermarking scheme. In Section 6, the experimental result is discussed. Finally in Section 7 conclusion of this work is drawn.

2 Related work

Over the past few years, watermarking techniques have emerged as a reliable approach for data authentication and copyright protection. Many effective watermarking techniques have been developed for the grayscale images, but for the color images, lots of work is needed and is the open research area . In the development of the watermarking scheme, there has been always a trade-off between robustness and imperceptibility. In this section, some of the relevant image watermarking techniques is discussed below.

In [24] a blind watermarking scheme is proposed based on tree structure of the DWT. In this technique perceptual model and synchronization template are used. Here using a hierarchical tree structure, watermarked coefficients are calculated. Al-Otum [3] has proposed a robust wavelet based watermarking scheme for color image. Here, imperceptibility is improved but robustness of watermark is sensitive against various attacks. Liu [16] has proposed DWT based watermarking scheme based on color visual model. This scheme gives acceptable perceptual quality but is sensitive to JPEG compression attack. In [41] using genetic algorithm color image watermarking is proposed. Experimental results shows that this scheme gives good imperceptibility with high time complexity. Also robustness of this scheme is not robust.

Selection of color space is major challenge for researcher [20]. Khalili and Asatryan [10] has done the detailed experimental performance analysis of CDMA watermarking techniques using DWT domain in the eight different color space. In this work except HSI and HSV color spaces other six color space satisfied the imperceptibility, robustness, security of watermarking scheme. Liu et al. [17] has proposed a dual blind watermarking technique for the protection of copyright and color image authentication. Here RGB color space is used for image authentication and YC_bC_r color space is used for copyright protection. Su et al. [38] presented a blind watermark technique where watermark is inserted into blue component of RGB image. Here, watermark is embedded in blue component to increase the robustness. Patvardhan et al. [23] proposed a robust watermarking technique for color images using SVD & DWT. Here, HH subband is selected to perform SVD operation. Further, to improve the security QR code is used. Prabha and Sam [25] have proposed Walsh Hadamard Transform (WHT) based blind color image watermarking scheme. Here, Triangular Vertex Transform (TVT) is utilized to convert the Red, Green and Blue channel coefficients to TVT Coefficients U, V and W respectively. Further, W coefficient is subdivided into blocks and is transformed using WHT.

Watermarking can also be classified either in adaptive or non-adaptive [14]. In adaptive watermarking scheme embedding parameters are specified according to its cover/host image [8, 14]. Kalra et al. [9] has proposed a color image watermarking technique based on the frequency domain in color space YC_bC_r. Two encryption scheme based on ECC was used for security of the watermark. Further, here embedding is carried adaptively in both low frequency and high frequency pixels. Vaidya et al. [42] has proposed an adaptive watermarking method in the $\mathrm{YC}_b\mathrm{C}_r$ color space. This method is suited for color images and is very robust. In this scheme author has calculated the embedding factor using Bhattacharya distance and exponential function. Sharma et al. [32] have proposed an adaptive robust image watermarking scheme using quality metrics optimized by ABC. Here, the host image is of the same size as the watermark used for embedding. Veni et al. [43] has presented hybrid (DWT-SVD) based image watermarking using the Oppositional Fruit Fly Algorithm (OFA). OFA is used for selection of optimal watermark embedding position. In [5] embedding region is selected adaptively based on the highest variance value of the block.

Sangeetha et al. [31] proposed a DWT domain based watermarking scheme using entropy and alpha blending. In this technique, watermarking is carried out using DWT decomposition. Here, the texture of the watermark is embedded into the highest entropy subband. In [11] color image watermarking is proposed using $\alpha - \beta$ blending scheme. Here, its experimental results depicts that this method is not robust against the JPEG compression attacks. In [30] DWT based watermarking scheme for grayscale image is presented. Further, DE technique is used to determine the alpha bending coefficient. This scheme gives good imperceptibility but is not robust against various attacks.

3 Preliminaries

3.1 Discrete wavelet transform (DWT)

DWT employs wavelet theory and provides a very energy compact representation of images [4]. Wavelets can be described as the tiny waves of frequency change. Images are decomposed hierarchically in DWT and deliver spatial as well as frequency description of images. Lots of image processing operation like watermarking employs DWT techniques because of the fact that it offers very good energy packaging. The time complexity of DWT of size M×N is O(MN) [34, 35]. Figure 1 represents one level of the wavelet decomposition.

3.2 Entropy

Entropy is used to enumerate how much information content is present in the image. It describes the amount of uncertainty/randomness contained in the image [12]. Entropy, also referred to as entropy of information and Shannon's entropy, measures the uncertainty of an information source. Shannon's entropy is defined as:

$$E(x) = -\sum p(x) \log p(x), \tag{1}$$

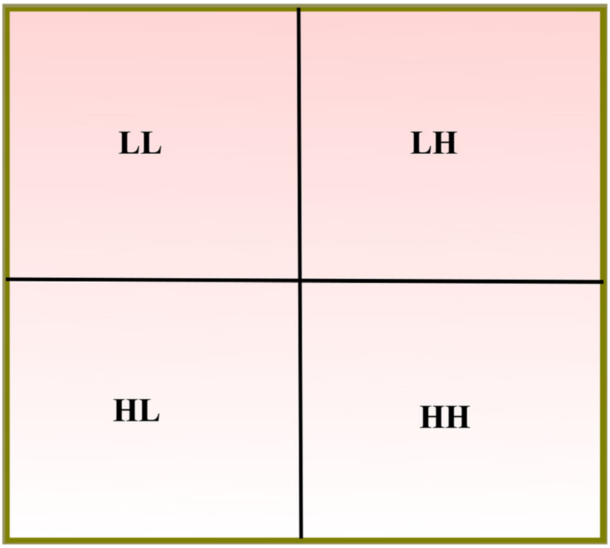

Fig. 1 One level wavelet decomposition

where p(x) denotes the probability associated with the intensity level. The higher the value of the entropy, the more detailed the image will be. In case of gray scale image the maximum entropy value is 8 , where as the minimum entropy value is 0.

3.3 Alpha blending

Alpha blending is a method in which two images are mixed to obtain the final [6, 33]. In context of watermarking alpha blending is a method of mixing cover image and watermark to get watermarked image. By keeping the balance between the cover as well as watermark image, alpha blending avoids the overflow of watermarked pixel values [7]. In case, if embedding & extraction is performed in the HH sub-band, embedding & extraction using alpha blending can be done using (2) and (3) respectively.

$$Wm = (\alpha \times HH) + ((1 - \alpha) \times W), \tag{2}$$

$$W = \frac{Wm - (\alpha \times HH)}{1 - \alpha}, \tag{3}$$

where Wm is watermarked Image, W is watermark, HH is diagonal sub-band of the Cover Image. α is blending factor ranges between 0 to 1.

4 Color band selection for watermarking

4.1 Color image watermarking

During last few years color image watermarking has emerged as a burning research topic for the researchers. Several works in the field of color watermarking is carried out in last few years [1, 2, 9, 11, 15, 17, 22, 23, 28, 32, 38, 39, 42, 44]. But still, lots of work is needed in this area [20]. The selection of color space in watermarking is very important because for different applications different color spaces gives better result. RGB color space is suitable for fragile watermarking whereas, for the robust watermarking scheme YC_bC_r color space is suitable [17, 23, 28].

Colors can be specified by the color spaces and these color spaces can be broadly classified into three categories: i) HVS based color space, ii) application specific color space and iii) CIE color space. RGB and YC_bC_r are the two main color space where the watermarking is carried out [17, 27, 28]. Among this YC_bC_r color space is most suitable color channel for watermarking with respect to robustness. Also, the information redundancy among the R, G, and B component of RGB image is comparatively close to each other. Due, to this fact the perceptibly of cover images got altered when watermark is inserted [15, 32].

4.2 Color band selection

In this section the proper justification is provided for the selection of Y component of YC_bC_r space for watermark embedding.

Let X is the Cover Image and A, B, C are its three color channel. X can be represented as function of three variable X = f(A, B, C). Since color channels in an image are not independent, we assume A, B, C a dependent random variable. Correlation between the pair (A,B), (B,C) and (A, C) are r_{AB} , r_{BC}, r_{AC}.

Let the mean of the color channel A, B, C is denoted by ($\bar{A}$, $\bar{B}$, $\bar{C}$) and after watermarking the color channel differ by ΔA, ΔB, ΔC from their means respectively. So, after watermarking A, B, C will be A = A + ΔA, B = B + ΔB, C = C + ΔC. Total modification in watermarked image will then be ΔX from its mean.

Now let us assume that the mean of X is $\bar{X}$. $\bar{X}$ is equal to the union of mean of the three separate color channel ($\bar{A}$, $\bar{B}$, $\bar{C}$) and ΔX = X - $\bar{X}$ = f(A, B, C) - f($\bar{A}$, $\bar{B}$, $\bar{C}$).

Now, the correlation coefficient r_{AB} , r_{BC}, r_{AC} between the pair (A,B) , (B, C) and (A, C) are represented by equation (4) equation (5) and equation (6) respectively.

$$r_{AB} = \frac{E[(A - \Delta A)(B - \Delta B)]}{\sigma_A . \sigma_B}, \tag{4}$$

$$r_{BC} = \frac{E[(B - \Delta B)(C - \Delta C)]}{\sigma_B . \sigma_C}, \tag{5}$$

$$r_{AC} = \frac{E[(A - \Delta A)(C - \Delta C)]}{\sigma_A . \sigma_C}, \tag{6}$$

where σ_A, σ_B, σ_C are the standard deviation of random variable A, B and C respectively.

For the robust watermarking there should be negligible alteration between the original and watermarked image, i.e. ΔX should be minimum. This means r_{AB} , r_{BC}, r_{AC} should be minimum. This implies that the change in one color channel due to the watermark insertion should be minimum in the other color channel. Correlation coefficient of the three common color channel (RGB, YC_bC_r and HSV) used for watermarking has been experimentally calculated over the 7 standard images and is depicted in Tables 1, 2 and 3 respectively. Here, CC_{RG}, CC_{RB}, CC_{BG} represents correlation coefficient of red and green color band, correlation coefficient of red and blue color band, correlation coefficient of blue and green band of RGB color model. Similarly, CC_{YCb}, CC_{YCr} and CC_{CbCr} represents correlation coefficient of Y and Cb color component, correlation coefficient of Y and Cr component, correlation coefficient of Cb and Cr component respectively. Whereas, CC_{HS}, CC_{SV} and CC_{HV} respectively denotes the correlation coefficient of H and S, correlation coefficient of S and V, correlation coefficient of H and V component of HSV color space.

Table 1 Correlation coefficient of R, G, B color channel

Image	CC_{RG}	CC_{RB}	CC_{BG}
Barbara	0.8392	**0.7417**	0.9446
Pepper	**0.2752**	0.3952	0.8379
Lena	0.8786	**0.6764**	0.9106
Jetplane	0.9212	**0.8410**	0.9380
Girl	0.7759	**0.5242**	0.6600
Lake	0.8868	**0.8270**	0.9563
Mandril	0.3481	**0.1258**	0.8273

Best values are highlighted in bold

Variation in one color channel of the original image due to addition of watermark should have least impact on the variation of other color channels [28]. Experimental results of Tables 1, 2 and 3 shows that YC_bC_r color channel is less correlated in comparison with RGB and HSV color space. This employs that in YC_bC_r color space color channels are less correlated and independent of other color channel. This employs in comparison of RGB and HSV color space there will be negligible alteration between the original and watermarked image in YC_bC_r color space. Due to this fact the watermarking schemes are comparatively more robust in YC_bC_r color space.

When the color is transformed into YC_bC_r color space, maximum energy is concentrated in Y channel. Its because Y channel is like the grayscale equivalent of the color image [28]. The entropy value of the various host image in different color channel is shown in Table 4. Experimental results of Table 4 shows that the entropy of Y channel is maximum in YC_bC_r color space. Human eye is less sensitive to high entropy areas[12]. Inserting watermarking in high entropy block results better imperceptibility.

From the above discussion it may be concluded that as YC_bC_r color space is least correlated, so robustness will be high in YC_bC_r color space. Further,in comparison with C_b and C_r component the entropy of Y component is high so the imperceptibility will be better in Y component. Therefore, trade-offs between imperceptibility and robustness will be balanced. Because of this fact, in this work Y component is chosen for watermarking.

5 Proposed techniques

In this work, color image watermarking in YC_bC_r color space using DWT is proposed. The proposed scheme is based on the concept of entropy and alpha blending. The watermark is embedded in the Y component of YC_bC_r color space. This color space is chosen because it

Table 2 Correlation coefficient of Y, C_b, C_r color channel

Image	CC_{YCb}	CC_{YCr}	CC_{CbCr}
Barbara	0.0609	0.0486	**−0.7318**
Pepper	−0.5744	**−0.6208**	0.2728
Lena	**−0.7408**	−0.1209	−0.4560
Jetplane	**−0.8181**	−0.2844	−0.0575
Girl	**−0.5572**	−0.1452	−0.1422
Lake	0.3526	**−0.8442**	−0.5621
Mandril	0.1157	−0.1526	**−0.7443**

Best values are highlighted in bold

Table 3 Correlation coefficient of H, S, V color channel

Image	CC_{HS}	CC_{SV}	CC_{HV}
Barbara	**−0.3622**	−0.1347	0.1244
Pepper	0.0929	**−0.5022**	−0.0335
Lena	0.5299	−0.6761	**−0.7039**
Jetplane	0.60941	**−0.8283**	−0.6661
Girl	−0.1281	**−0.4460**	−0.1503
Lake	0.0444	**−0.7808**	0.0372
Mandril	**−0.3796**	0.3202	0.0579

Best values are highlighted in bold

has the least correlated color channel as experimentally proved in Section 4.2. The proposed techniques is consist of mainly two parts: watermark embedding and watermark extraction. The proposed watermark embedding is described in Section 5.1, whereas watermark extraction techniques is described in Section 5.2. Figure 2 shows the proposed watermark embedding process, whereas Fig. 3 depicts watermark extraction process.

5.1 Watermark embedding

To embed the watermark, initially the RGB Cover Image (size 512 × 512) is taken and converted to YC_bC_r color space. This is followed by the application of Level 1 DWT on the Y component. After applying the 1 Level DWT, Y component is partitioned into 64 uniform non-overlapping blocks of size 32 × 32. A watermark (size 64 × 64) is taken and 1 level of DWT is applied. Now, HH component of the watermark is inserted into HH block of cover image of Y component with the highest entropy value. The embedding is done using the alpha blending. After embedding process, the resulted image is converted into RGB color space and is watermarked image.

Let CI_{RGB} is RGB color image of size $M \times N$ and W is grayscale watermark of size $m \times n$. DWT based watermark embedding steps shown in Fig. 2 is discussed below.

Step 1. Read the color cover imgae CI_{RGB} and transformed it from RGB to YC_bC_r color space

$$[CI_Y, CI_{Cb}, \text{ and } CI_{Cr}] = YC_bC_rConversion(CI_{RGB})$$

Table 4 Entropy analysis of various color channels

Color Band	Barbara	Pepper	Lena	Jetplane	Girl	Lake	Mandril
R	7.5775	7.3388	7.2531	6.7178	4.3374	7.3124	6.9294
G	7.4194	**7.4963**	**7.5940**	**6.7990**	**6.6900**	7.6461	6.3175
B	7.5160	7.0583	6.9680	6.2138	6.4289	7.2137	7.2895
Y	7.2191	7.3746	7.2257	6.4846	6.3825	7.2659	6.9580
Cb	4.9976	5.6377	5.4633	4.3678	5.2561	5.4451	6.1355
Cr	5.1977	6.4809	5.4242	3.7157	5.1698	6.0886	6.1331
H	5.5689	6.1877	5.8717	6.6933	5.4598	7.1245	7.0356
S	7.6121	7.2514	7.3538	5.8247	6.4557	**7.6806**	**7.6031**
V	**7.5727**	7.2142	7.2479	6.3127	4.2807	7.3303	6.9542

Best values are highlighted in bold

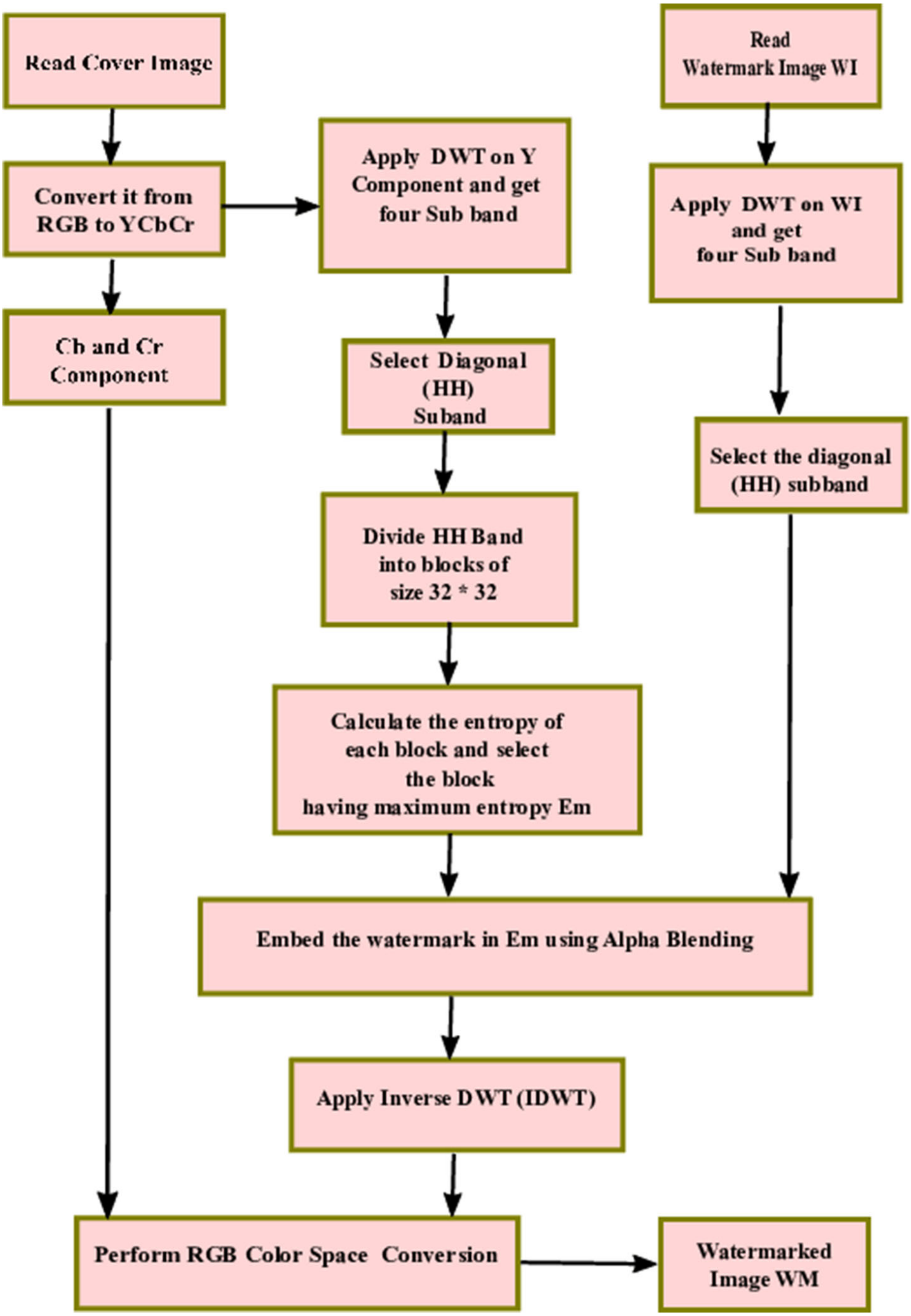

Fig. 2 Block diagram of proposed watermark embedding scheme

Here RGB component is separated in three different component Y, C_b and C_r and is denoted by CI_Y, CI_{Cb}, CI_{Cr}

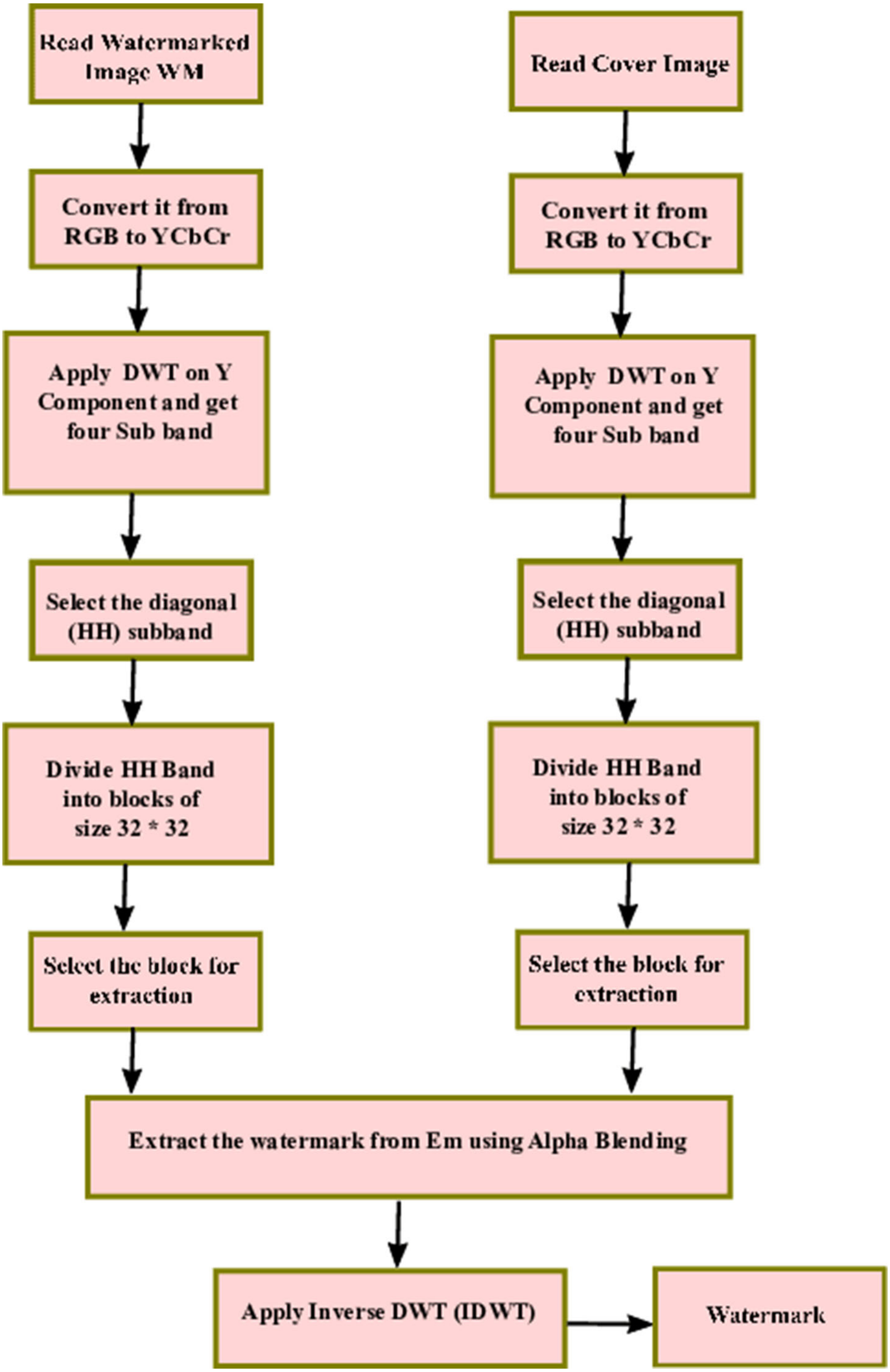

Fig. 3 Block diagram of proposed watermark extraction scheme

Step 2. Select Y Channel (CI_Y) of YC_bC_r color space and apply first level of DWT over it.

In this step Y component is selected and first level of DWT decomposition is applied on Y Channel component (CI_Y) to get approximation component (LL), horizontal detail component (HL), vertical detail component (LH) and diagonal detail component (HH).

$$[\Phi_Y^A(\mathrm{x, y}), \Phi_Y^H(\mathrm{x, y}), \Phi_Y^V(\mathrm{x, y}), \Phi_Y^D(\mathrm{x, y})] = \mathrm{DWT}(\mathrm{CI}_Y)$$

Here, Φ_Y^A (x,y), Φ_Y^H (x,y), Φ_Y^V (x,y), Φ_Y^D (x,y) are LL, HL, LH and HH of cover image respectively.

Step 3. Read a grayscale watermark image of size 64 × 64 and apply first level DWT on watermark image.

$$[\Phi_W^A(\mathrm{x, y}), \Phi_W^H(\mathrm{x, y}), \Phi_W^V(\mathrm{x, y}), \Phi_W^D(\mathrm{x, y})] = \mathrm{DWT(W)}$$

Here, Φ_W^A (x,y), Φ_W^H (x,y), Φ_W^V (x,y), Φ_W^D (x,y) are LL, HL, LH and HH component of watermark image respectively.

Step 4. Divide the Y component of cover image into non-overlapping blocks of size 32×32 and calculate the entropy of each block. Further, select the block with the highest entropy value E_{max} for watermark insertion.

Step 5. Embed the HH_1 of watermark into the block E_{max} of cover image using (7)

$$WM_Y(x, y) = (\alpha \times E_{max}) + (1 - \alpha) \times \Phi_W^D(x, y). \quad (7)$$

Here, α is scaling factor and E_{max} is block of cover image in which watermark is embedded and $\Phi_W^D(x, y)$ is diagonal component of watermark.

Step 6. Apply the inverse DWT

Inverse Discrete Wavelet Transom (IDWT) is applied to get Watermarked Image

$$WM_{YCbCr} = \mathrm{IDWT}[\Phi_W^A(\mathrm{x, y}), \Phi_W^H(\mathrm{x, y}), \Phi_W^V(\mathrm{x, y}), WM_Y(x, y)]$$

Step 7. Covert watermarked image into RGB color space

Watermarked image is reconstructed by transforming YC_bC_r watermarked image (WM_{YCbCr}) to RGB watermarked image (WM_{RGB}).

$$WM_{RGB} = \mathrm{RGBConversion}(WM_{YCbCr}, CI_{Cb}, CI_{Cr})$$

5.2 Watermark extraction

Let WM_{RGB} represents watermarked image of size $M \times N$. DWT based watermark extraction steps shown in Fig. 3 is discussed below.

Step 1. Read the watermarked image WM_{RGB} and convert it into YC_bC_r color space.

Here, the watermarked image is converted into YC_bC_r color space and separated into three different component Y, C_b and C_r and is denoted by WM_Y, WM_{Cb}, WM_{Cr}

$$[WM_Y, WM_{Cb}, WM_{Cr}] = YC_bC_rConversion(WM_{RGB})$$

Step 2. Select Y component of watermarked image and apply one level of DWT on it

The Y component of watermarked image is selected and is decomposed into LL, HL, LH and HH component.

$$[\Phi_{WMY}^A(\mathrm{x, y}), \Phi_{WMY}^H(\mathrm{x, y}), \Phi_{WMY}^V(\mathrm{x, y}), \Phi_{WMY}^D(\mathrm{x, y})] = \mathrm{DWT}(\mathrm{WM}_Y)$$

Here, Φ_{WMY}^A (x,y), Φ_{WMY}^H (x,y), Φ_{WMY}^V (x,y), Φ_{WMY}^D (x,y) is respectively LL, HL, LH, and HH component of WM_Y

Step 3. Read the cover image and convert it into YC_bC_r color space

$$[CI_Y, CI_{Cb}, \text{ and } CI_{Cr}] = YC_bC_rConversion(CI_{RGB})$$

Step 4. Select Y component of cover image and apply first level of DWT on it

$$[\Phi_Y^A(\text{x, y}), \Phi_Y^H(\text{x, y}), \Phi_Y^V(\text{x, y}), \Phi_Y^D(\text{x, y})] = \text{DWT}(\text{CI}_Y)$$

Step 5. Divide the watermarked image and cover images into non-overlapping blocks

Diagonal component of both the watermarked image and the cover image is divided into the non overlapping block of size 32 × 32 and the same block is selected where the watermark was inserted.

Step 6. Extract the watermark using alpha blending

The extraction of watermark is carried out using (8)

$$\Phi_W^D(x, y) = \frac{WM_Y(x, y) - (\alpha \times HH_{Emax})}{1 - \alpha}. \tag{8}$$

Step 7. Apply Inverse DWT to get the original watermark W.

$$\text{W} = \text{IDWT}[\Phi_W^A(\text{x, y}), \Phi_W^H(\text{x, y}), \Phi_W^V(\text{x, y}), \Phi_W^D(\text{x, y})]$$

Finally, the watermark is obtained by applying Inverse DWT.

6 Result & discussion

In this experiment, seven standard color images (each of size 512 × 512) have been used as a cover images. A grayscale image of (size 64 × 64) was used as a watermark. In this section imperceptibility analysis, robustness analysis, computational complexity analysis and payload analysis of the proposed scheme is carried out. Further, the comparative analysis with the state-of-the-art schemes are also shown in this section. Figure 4 depicts sample cover images and the watermark used in this work, whereas Fig. 5 depicts sample watermarked images.

PSNR, SSIM, NCC, BER and computational time are the different objective performance metrics used to evaluate the effectiveness of the proposed techniques. High PSNR values and SSIM value closer to 1 specifies that the watermarked image is indistinguishable to the cover image. Robustness of the proposed system is tested over several attacks, like a) no attack, b) snp(0.02), c) snp(0.05), d)Gaussian noise, e) speckle noise, f) sharpening, g) histogram equalization, h) Gaussian filter, i) median filter, j) rotation attack 10°, k) crop 10%, l) jpeg compression (QF = 90%), m) jpeg compression (QF = 70%), n) jpeg compression (QF = 50%).

6.1 Imperceptibility analysis

Imperceptibility is a major feature of the watermarking scheme. In this sub section the imperceptibility analysis of the proposed scheme is done. PSNR and SSIM are most commonly used objective performance metrics to examine the imperceptibility of the watermarking techniques. In this work, PSNR, SSIM, SNR, MSE, MAE, and NCC objective parameters are used to evaluate the perceptual transparency of the proposed scheme. In general, if the PSNR value is $\geq$ 48 dB that means the quality of image is excellent and there is no changes which can be noticed [20]. PSNR value in between 35 dB to 48 dB means good image quality and PSNR value ranging from 29 dB to 35 dB signifies acceptable image quality. PSNR value below 25 dB means the image is perceptible. PSNR value of the proposed scheme is in between 50.1186 dB and 52.2229 dB, whereas the average PSNR value is

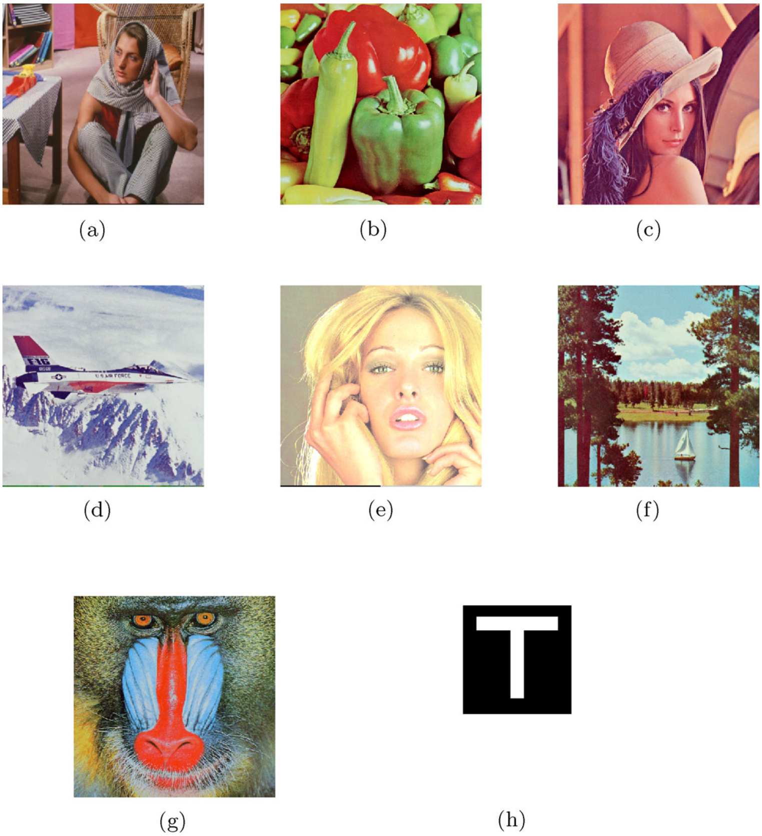

Fig. 4 Cover images and watermark

51.6145 dB. The average SSIM value of the proposed scheme is 0.9992 which is very close to the ideal value which indicates that watermarked images have no significant distortions.

Table 5 shows the result of various imperceptibility metrics value of the proposed scheme. From Table 5 it is observed that maximum PSNR value is achieved on the Girl image whereas the minimum PSNR is for mandrill image. Whereas, the SSIM value is

Table 5 PSNR, SSIM, SNR, MSE, MAE and NCC values of cover and watermarked image

Image	PSNR	SSIM	SNR	MSE	MAE	NCC
Barbara	51.3375	0.9993	44.9300	0.4779	0.0718	**0.9999**
Pepper	51.9846	**0.9998**	46.0603	0.4117	0.0677	**0.9999**
Lena	51.8941	**0.9998**	46.7565	0.4204	0.0676	**0.9999**
Jetplane	51.9621	0.9971	49.2741	0.4139	0.0674	**0.9999**
Girl	**52.2229**	0.9997	**50.3869**	**0.3898**	**0.0558**	0.9998
Lake	51.7821	0.9995	46.6310	0.4314	0.0682	**0.9999**
Mandril	50.1186	0.9997	44.3768	0.6327	0.0757	**0.9999**

Best values are highlighted in bold

highest for Pepper and Lena image. Also, Table 5 depicts that average PSNR, average SSIM, average SNR, average MSE, average MAE and average NCC of the cover image and the watermarked image of proposed scheme is 51.6145 dB, 0.9992, 46.9165 dB, 0.4539, 0.0677 and 0.9998 respectively.

6.2 Robustness analysis

The robustness of a watermarking scheme is in its ability to withstand the various attacks on it. To check the robustness of our proposed method, the watermarked images are subjected to many attacks. Some of these include JPEG Compression, cropping, rotation, addition of salt & pepper noise etc. The Lena image is used as an example here. Figure 6 represents the attacks on the watermarked image and Fig. 7 represents the extracted watermark. Here [a-n] represents no attack, snp (0.02), snp (0.05), Gaussian noise, speckle noise, Gaussian filtering, median filtering, histogram equalization, sharpening, rotation 10°, crop 10%, JPEG compression (QF = 90%), JPEG compression (QF = 70%) and JPEG compression (QF = 50%). NCC and BER is used as a performance metric for robustness. Table 6 shows PSNR value of the cover image and watermarked image on various attack. NCC and BER of the original watermark and the extracted watermark of proposed scheme is depicted in Tables 7

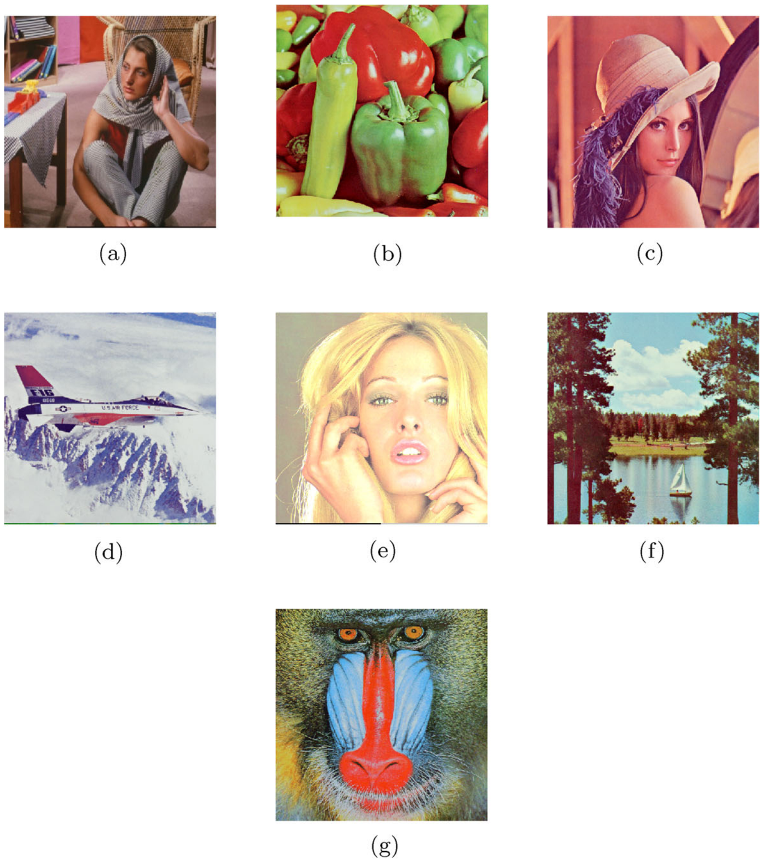

Fig. 5 Sample watermarked images

Fig. 6 Sample attacked Lena images

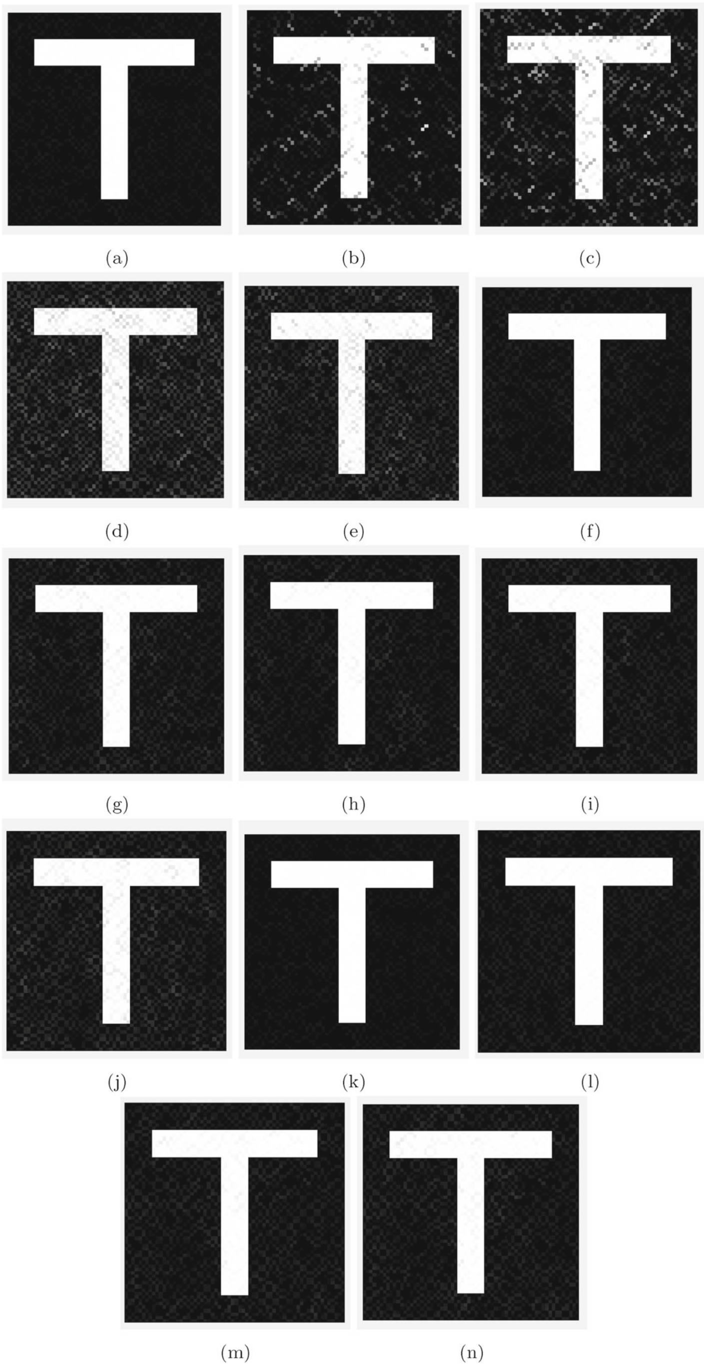

Fig. 7 Extracted Watermark with (a) no attacks, (b) snp(0.02), (c) snp(0.05), (d) Gaussian noise, (e) Speckle noise, (f) Gaussian filtering, (g) Median filtering,(h) Histogram equalization, (i) Sharpening, (j) Rotation (10°),(k) Cropping, (l) JPEG compression (QF = 90%),(m) JPEG compression (QF = 70%),(n) JPEG compression (QF = 50%)

Table 6 PSNR value of cover image and watermarked image on various attacks

Attack	Barbara	Pepper	Lena	Jetplane	Girl	Lake	Mandril
a	51.3375	51.9846	51.8941	51.9621	**52.2229**	51.7821	50.1186
b	**22.4254**	21.8476	22.1693	21.8840	21.3319	21.9436	22.1809
c	**18.2720**	17.9630	18.1745	17.9120	17.4039	17.9803	18.2616
d	19.1126	19.1968	19.3273	19.5239	**20.6639**	19.2960	19.2146
e	**19.5694**	19.2055	18.7795	16.4192	16.3502	18.6931	19.1583
f	37.1428	38.5358	**40.6700**	40.5682	39.6229	36.0618	30.6384
g	28.7697	31.9456	33.7922	**34.2338**	32.3726	28.5467	22.6048
h	18.9111	22.2601	22.8089	11.2363	9.8460	**27.9494**	21.5395
i	30.8495	34.1441	35.1195	33.3285	**35.3626**	31.0564	25.4881
j	12.3800	11.4436	12.5446	10.9816	**12.6583**	10.7858	12.6180
k	17.2401	15.6155	15.8083	12.8027	12.6733	16.5339	**16.8056**
l	**43.8853**	35.1230	37.6568	40.7213	38.1127	32.3143	27.5003
m	**35.5901**	32.3613	34.3002	35.5046	34.2559	28.7473	23.9245
n	32.3179	30.9821	32.7572	**32.9955**	32.7912	27.1909	22.4798

Best values are highlighted in bold

and 8 respectively. The watermarking scheme is said to be robust if the NCC value closer to 1 against the attacks. In this proposed work, for no attacks condition the average NCC value of watermark and extracted watermark is 1. Whereas, the average BER under no attack is 0.0422. It is clear from the experimental result that proposed watermarking technique is very robust against different attacks.

To show the trade-off between the robustness and imperceptibility on the addition of attacks, a graph is plotted between PSNR value of attacked images and NCC of extracted

Table 7 NCC values of extracted watermark on various attacks

Attack	Barbara	Pepper	Lena	Jetplane	Girl	Lake	Mandril
a	**1**	**1**	**1**	**1**	**1**	**1**	**1**
b	0.9910	**0.9926**	0.9895	0.9898	0.9861	0.9884	0.9896
c	0.9790	0.9815	0.9704	0.9782	0.9656	0.9717	**0.9818**
d	0.9867	**0.9886**	0.9878	0.9882	0.9927	0.9875	0.9880
e	0.9826	0.9851	**0.9945**	0.9809	0.9725	0.9917	0.9835
f	0.9992	0.9997	0.9998	**0.9999**	0.9995	0.9997	0.9971
g	0.9950	0.9991	0.9991	**0.9993**	0.9987	0.9985	0.9869
h	0.9989	**0.9999**	0.9995	0.9934	0.9972	0.9997	0.9973
i	0.9976	0.9992	0.9995	**0.9996**	0.9987	0.9990	0.9915
j	0.9929	**0.9989**	0.9979	0.9983	0.9978	0.9971	0.9830
k	**1**	**1**	**1**	**1**	**1**	**1**	0.9945
l	**0.9999**	0.9998	**0.9999**	**0.9999**	**0.9999**	0.9995	0.9985
m	0.9992	0.9992	0.9995	**0.9996**	0.9994	0.9988	0.9928
n	0.9970	0.9991	0.9992	**0.9994**	0.9986	0.9986	0.9888

Best values are highlighted in bold

Table 8 BER values of extracted watermark on various attacks

Attack	Barbara	Pepper	Lena	Jetplane	Girl	Lake	Mandril
a	0.0430	0.0429	0.0419	**0.0395**	0.0421	0.0425	0.0438
b	0.0748	0.0753	0.0701	0.0696	0.0695	**0.0688**	0.0749
c	0.1078	0.1093	0.1038	**0.1018**	0.1016	0.1063	0.1025
d	0.1563	0.1542	0.1535	0.1579	**0.1377**	0.1539	0.1558
e	0.1601	0.1602	**0.1313**	0.1596	0.1664	0.1328	0.1564
f	0.1017	0.0804	0.0676	**0.0595**	0.0815	0.0775	0.1282
g	0.1372	0.1030	0.0940	**0.0860**	0.0945	0.1044	0.1517
h	0.1057	**0.0569**	0.0770	0.0956	0.1198	0.0767	0.1136
i	0.1193	0.0996	0.0890	**0.0867**	0.0986	0.0971	0.1483
j	0.1367	**0.1082**	0.1161	0.1116	0.1136	0.1213	0.1612
k	0.0430	0.0429	0.0419	**0.0395**	0.0421	0.0425	0.0821
l	**0.0574**	0.0763	0.0714	0.0696	0.0695	0.0922	0.1146
m	0.0985	0.1035	0.0906	**0.0861**	0.0973	0.1078	0.1439
n	0.1259	0.1021	**0.0908**	0.0909	0.1055	0.1069	0.1521

Best values are highlighted in bold

watermark from this attacked image is shown in Figs. 8 and 9. Standard images like,Barbara, Pepper, Lena, and Jetplane are used for analysis. In Fig. 8 plot is drawn for snp attacks with varying density value from 0.01 to 0.05, whereas Fig. 9 depicts the plot for JPEG compression attacks with with varying the QF value from 90% to 50%.

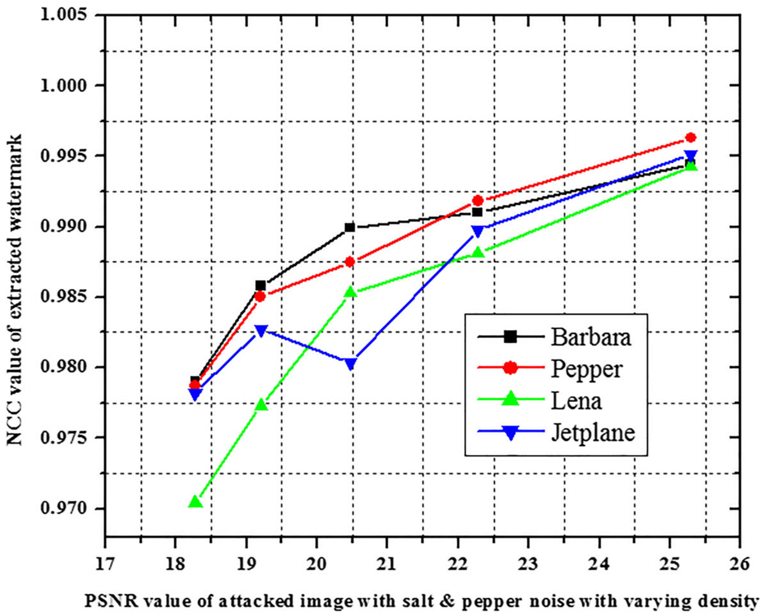

Fig. 8 Plot for NCC VS PSNR in case of snp attack with varying density

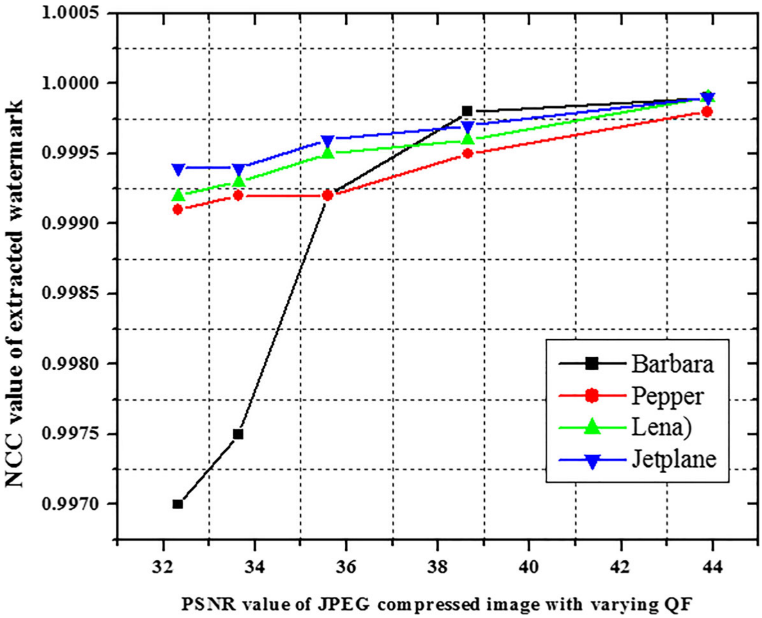

Fig. 9 Plot for NCC VS PSNR in case of JPEG compression attack with varying QF

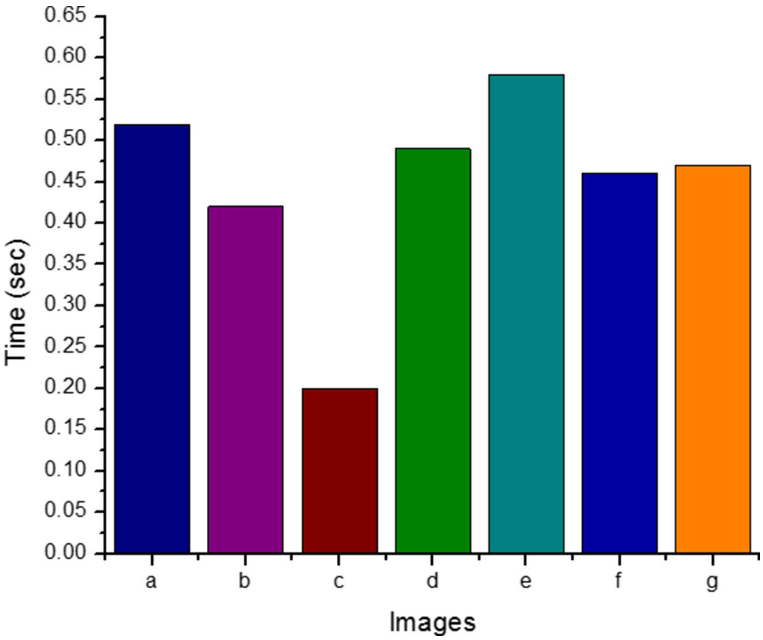

Fig. 10 Time Complexity of the proposed scheme

6.3 Computational complexity

In this work, experiment is conducted using Matlab on a computer with 4 GB RAM, Intel i7 processor and 3.40 GHz clock speed. The average computational time of the proposed scheme is 0.453745 secs. Figure 10 shows the complexity of the proposed scheme on various images. As, the watermark is inserted into a block of cover image, computational time of the proposed scheme is very less. Here, the size of cover image is $M \times N$ and the size of watermark image is $m \times n$, where $M > m$ and $N > n$. So, the time complexity of DWT watermarking is O(MN). Further the dimension of cover image in this scheme is same i.e. (M=N), thus the overall complexity of proposed scheme in O(M^2)

6.4 Payload analysis

In this proposed scheme the color cover image is of size 512 × 512 and grayscale watermark is of size 64×64. So, the embedding payload of the proposed watermarking scheme is 0.04166 bpp and is calculated as:

$$(64 \times 64 \times 8)/(512 \times 512 \times 3) = 0.04166 \text{ bpp}$$

Similarly the embedding capacity of the proposed watermarking scheme is 4096.

6.5 Comparative analysis

In this section the comparative analysis of proposed scheme is done with some of the recent state-of-the-art approaches [2, 11, 17, 18, 20, 22, 23, 25, 29, 32, 38]. The comparative analysis of proposed scheme imperceptibility with the state-of-the-art schemes is depicted in Table 9. PSNR (dB) and SSIM are two metrics used in Table 9 for comparative analysis. Whereas, NCC is used for comparative analysis of robustness with some of existing schemes is shown in Table 10.

The average PSNR value of the proposed technique is 51.6145 dB whereas the average SSIM value is 0.9992. It clear from Table 9 that only [11] scheme gives the better SSIM and PSNR value than our proposed scheme. Moreover, the SNR of proposed scheme is better than Koley scheme [11]. The SNR of the proposed scheme is 46.7565 dB whereas, SNR of [11] scheme is 44.8871 dB.This proves the perceptual excellence of the proposed scheme. Experimental results shows that PSNR and SSIM value of the proposed scheme is better than various state-of-the-art schemes.

The robustness of the proposed scheme under a number of attacks is compared with other schemes and is shown in Table 10. Table 10 shows that the NCC value of the proposed scheme is higher than the most of state-of-the-art schemes. The experimental results shows that in comparison with Koley [11] and Su et al. [38] techniques the proposed scheme is more robust against the JPEG compression attack. Liu et al. [17] and Pandey et al. [22] scheme are based on DWT techniques and watermark is embedded in YC_bC_r color space.

Table 9 Comparative analysis of proposed scheme with state-of-the-art schemes for imperceptibility

	[23]	[32]	[25]	[20]	[2]	[18]	[11]	[29]	[38]	[22]	[17]	Proposed
PSNR	47.4772	**77.4875**	39.976	40.30	47.64	41.24	54.9408	42.2198	49.9898	37.87	40.85	51.8941
SSIM	–	0.9940	0.9874	–	0.9725	0.9979	**1**	–	0.9872	0.99	0.9814	0.9998

Best values are highlighted in bold

Table 10 Comparative analysis of proposed scheme with state-of-the-art schemes for robustness

Attacks	[23]	[32]	[25]	[20]	[2]	[18]	[11]	[29]	[38]	[22]	[17]	Proposed
a	0.9999	—	**1**	**1**	**1**	**1**	**1**	**1**	**1**	—	0.99	**1**
b	0.9874	0.9966	0.8945	—	—	—	—	—	**1**	0.9981	0.95	0.9895
c	—	—	—	0.9488	0.9710	—	**0.9893**	—	—	—	—	0.9704
d	0.9879	0.9914	0.9363	**0.9941**	—	0.9924	0.9382	0.8967	—	—		0.9878
e	—	—	0.9194	0.8780	0.9129	—	—	0.8838	—	—	—	**0.9945**
f	—	0.9959	**1**	**1**	0.9993	0.9248	—	**1**	—	—	0.93	0.9998
g	0.9971	0.9955	—	0.9961	0.9435	0.9324	**1**	0.9950	0.9977	—	0.94	0.9991
h	0.9308	0.9725	0.9186	**1**	—	0.9731	**1**	0.9313	—	—	0.87	0.9995
i	—	0.9914	0.9596	**1**	0.9455	0.9645	0.9686	**1**	—	—	—	0.9995
j	**0.9993**	—	0.9569	—	—	0.9548	0.9389	—	—	—	—	0.9979
k	—	—	0.9438	—	—	—	—	—	—	0.9998	—	**1**
l	0.9908	0.9964	0.9979	**1**	—	**1**	—	–	0.9931	0.9967	—	0.9999
m	0.9902	0.9962	—	**1**	0.8314	—	—	**1**	0.7650	0.9711	—	0.9995
n	0.9895	0.9960	—	**1**	—	—	0.2252	**1**	0.7166	—	—	0.9992

Best values are highlighted in bold

Experimental results shows that proposed scheme gives better robustness and imperceptibility than Pandey et al. [22] and Liu et al. [17] scheme. Also, it is clear from the experimental result that the proposed scheme is more robust against a variety of image processing attacks, image enhancement attacks geometric attacks, and JPEG compression attacks.

Time complexity of the watermarking scheme is used to compare the computation efficiency of watermarking scheme. The average computational time of the proposed scheme is 0.453745 sec. Whereas, the time complexity of proposed DWT based watermarking scheme is O(M^2).

In [29] and [20], block based DCT watermarking technique is used. Therefore, its time complexity is O(L^2 log L) where 'L' is size of the block. Whereas, [22, 23] and [32] scheme are based on wavelet and SVD, therefore its complexity is O(M^3). The time complexity of [11] and [25] techniques is O(M^2). From the above discussion, it is clear that proposed color image watermarking scheme is computationally efficient. Low computational cost, better PSNR value and high robustness are the major highlight of the proposed scheme. As imperceptible, computationally efficient, and robust color image watermarking scheme, the proposed scheme is more appropriate for real-life applications such as copy control, ownership establishment, image authentication etc.

Experimental results of Tables 5–8 and Fig. 8–10 proves that proposed scheme satisfy the trade-offs between imperceptibility and robustness, and computational complexity. Further, Tables 9 and 10 proves the supremacy of the proposed scheme with recent state-of-the-art. PSNR and SSIM value of [11] is comparatively better than the proposed scheme but its robustness against JPEG compression attack is very poor. Moreover, the proposed scheme gives better robustness along with excellent imperceptibility.

7 Conclusion

A DWT based color image watermarking scheme in YC_bC_r color space has been proposed in this work. In this work, the block of HH_1 sub-band has been utilized to embed the watermark. Objective evaluation metrics like PSNR, SSIM, SNR, MSE, MAE, and NCC have been used to evaluate the imperceptibility of the proposed technique. On the other hand, NCC & BER are used to evaluate robustness of proposed scheme. Experimental results show that the method proposed is robust against a variety of image processing and geometric attacks. Compared with other techniques, our proposed technique gives better robustness against JPEG compression attacks. Low computational cost, better PSNR value and high robustness are the major highlight of the proposed scheme. Experimental results also proves that proposed scheme satisfy the trade-offs between imperceptibility, robustness, payload and computational complexity.

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