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ROBUST COLOR IMAGE WATERMARKING SCHEMES IN THE WAVELET DOMAIN

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Abstract
In this paper, two approaches for color image watermarking in the wavelet domain are proposed. The first approach utilizes only the chrominance content of the color image for watermarking after performing a single level DWT (Discrete Wavelet Transform) decomposition and hence named as DWTC whereas the second approach utilizes both the luminance and chrominance content for watermarking and hence termed as DWTLC. Watermark which is a logo is scrambled before embedding to increase its robustness. Watermarking is done on the approximation band coefficients chosen randomly by a function in L*a*b* space. Both the proposed approaches result in watermarked images of high quality. The robustness of both the approaches is verified by the conduct of various attacks on the watermarked images and is compared with an existing SCDFT based approach and a DWT based approach. Experimental results show that DWTC is robust to non geometric attacks like filtering, blurring, sharpening, histogram equalization, JPEG compression and to geometric attacks like additive noise and scaling. DWTLC watermarking also shows robustness to all the above attacks. Further, both the approaches resist collusion attack even with a minimum number of colluders and with increasing number of colluders there is much distortion in the visual quality of the colluded images.

Keywords:
DWT, Luminance, Chrominance, Attacks, Collusion

1. INTRODUCTION

With the development of multimedia technology and with the growth of Internet communications, digital media can be easily duplicated, distributed and tampered. Piracy of the digital media without appropriate permission from rightful owners not only deprives rights of creators but also harms innovations. Digital watermarking technique provides an approach to deal with these problems. Digital image watermarking is a process of embedding an unperceptive signature or a copyright message such as a logo into a digital image. The advantages of watermarking are its imperceptibility and robustness. Also, an effective watermarking scheme should satisfy the requirements of security, unambiguity and low computational complexity. Watermarking techniques developed for images are mainly classified as visible and invisible approaches. While visible watermarking helps in covert assertion, the invisible methods help in protecting copyrights. Depending on the application, watermarking schemes are classified as robust and fragile watermarking where the former is used for copyright protection and latter for data authentication.

Digital image watermarking techniques mainly fall into two broad categories namely: spatial domain and transform domain techniques. Spatial domain techniques embed the watermark by directly modifying the pixel values of the host image whereas transform domain techniques convert the host image into frequency domain by transformation methods such as the Discrete Cosine Transform (DCT), discrete Fourier transform (DFT) or Discrete Wavelet Transform (DWT), Discrete Hadamard Transform (DHT), Discrete Laguerre Transform (DLT) etc. The transform domain coefficients are then altered by the watermark. Transform domain techniques are very robust against attacks involving image compression and filtering because the watermark is actually spread throughout the image, not just operating on an individual pixel [1]. Among the transform domain watermarking techniques, Discrete Wavelet Transform (DWT) based watermarking techniques are the best because of the following advantages: space frequency localization, multi resolution representation, best HVS modeling, linear complexity and adaptivity [2].

In general, color image watermarking algorithms work by applying variances to pixel colors that cannot be discerned by the human eye. Most current watermarking techniques focus mainly on watermarking grey scale images. The extension to color is done by processing each component or any one component of the RGB color space separately [3].

1.1 RELATED RESEARCH

Researchers have proposed various color image watermarking schemes in the wavelet domain. Amit Phadikar et al. [4] have developed an approach that embeds the watermark in the wavelet domain by manipulating the coefficients in a 4×4 block. Only the blue channel is used for watermark embedding as it is less sensitive to HVS. In the scheme proposed by Shang-Lin Hsieh et al. [5], the original image is transformed to YCbCr space to create a sampling plane and DWT is used to extract features from the plane to generate a principal share image which is then embedded into the host image. Using DWT, in Jiang-Bin Zheng and Sha Feng's approach [6], a watermarking template is generated referring to one channels' DWT coefficients of the image and this template is embedded into other DWT channel of the same image. The watermark information which includes a section of the template information is embedded into the low frequency coefficients of the Y component in YUV color space in [7]. Peter Foriš and Dušan Levický [8] have developed a scheme wherein the watermark is embedded into transform domain of a chosen color image component in a selected color space. It uses a combination of HVS models to select perceptually significant transform coefficients and at the same time to determine the bounds of modification of selected coefficients. The method proposed by Qiujuan Liang, Zhizhong Ding [9] embeds a pseudorandom sequence representing one bit of the original watermark into a four-fork tree in the DWT of Y component of YUV. This distributes the information of one bit into several frequency sub

bands, such as low, intermediate and high frequency sub band, which improves the robustness of watermark against different attacks. In the scheme proposed by P. Ramana et al. [10] watermarking is done by modifying the frequency coefficients of the image, based on human visual systems perception of image content such that its amplitude is kept below the distortion sensitivity of the pixel and thus preserving the image quality.

1.2 CONTRIBUTION TO THE PAPER

In the field of color image watermarking, most color image watermarking algorithms consider only the luminance content for watermarking. In this work, the proposed approaches DWTC utilize the chrominance and DWTLC utilizes both the luminance and chrominance content for watermarking. Watermarking is done in L*a*b* color space. A significant improvement in the peak-signal to noise ratio (PSNR) of the watermarked image and robustness to attacks is achieved with the use of DWT than an existing work based on Spatio Chromatic Discrete Fourier Transform (SCDFT) [13]. Also, the proposed approaches are shown to be robust to large classes of attacks than the DWT approach proposed by Ramana et al. [10]. Especially, the proposed schemes are resistant to JPEG compression and collusion attacks.

The rest of the paper is organized as follows: Section 2 deals with the Discrete Wavelet Transform. Section 3 describes the proposed watermarking approaches. Experimental results are discussed in Section 4. Section 5 deals with conclusion and future work.

2. THE DISCRETE WAVELET TRANSFORM

The Discrete Wavelet Transform (DWT), which is based on sub band coding, is found to yield a fast computation of Wavelet Transform. It is easy to implement and reduces the computation time and resources required. With DWT, a time-scale representation of the digital signal is obtained using digital filtering techniques. The signal to be analyzed is passed through filters with different cutoff frequencies at different scales.

Wavelets can be realized by iteration of filters with rescaling. The resolution of the signal, which is a measure of the amount of detail information in the signal, is determined by the filtering operations, and the scale is determined by up sampling and down sampling (sub sampling) operations. DWT is computed by successive low pass and high pass filtering of the discrete time domain signal as shown in Fig.1. This is called the Mallat algorithm or Mallat-tree decomposition. In the figure, the signal is denoted by the sequence x (n), where n is an integer. The low pass filter is denoted by g (n) while the high pass filter is denoted by h (n). At each decomposition level, the half band filters produce signals spanning only half the frequency band. This doubles the frequency resolution as the uncertainty in frequency is reduced by half. In accordance with Nyquist's rule, if the original signal has a highest frequency of π, which requires a sampling frequency of 2π radians, then it now has a highest frequency of $\pi/2$ radians. It can now be sampled at a frequency of π radians thus discarding half the samples with no loss of information. This decimation by 2 halves the time resolution as the entire signal is now represented by only half the number of samples. Thus, while the half band low pass filtering removes half of the frequencies and thus halves the resolution, the decimation by 2 doubles the scale. A single level of decomposition can mathematically be expressed as in Eq. (1):

$$y_{high}[k] = \sum_n x(n) \cdot g(2k-n)$$
$$y_{low}[k] = \sum_n x(n) \cdot h(2k-n) \quad (1)$$

With this approach, the time resolution becomes arbitrarily good at high frequencies, while the frequency resolution becomes arbitrarily good at low frequencies. The filtering and decimation process is continued until the desired level is reached. The maximum number of levels depends on the length of the signal. The DWT of the original signal is then obtained by concatenating all the coefficients, g[n] and h[n], starting from the last level of decomposition.

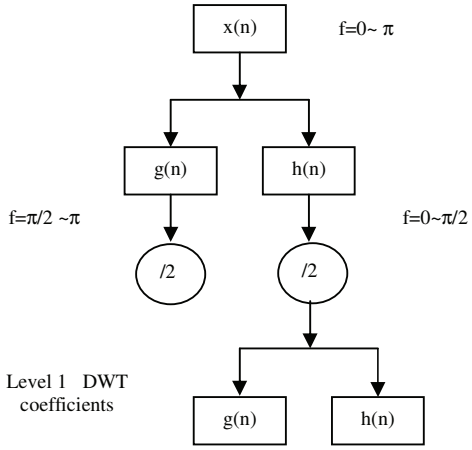


Fig.1. Single Level DWT decomposition

The Fourier transform retrieves only the global frequency content of a signal and the time information is lost. This is overcome by the short time Fourier transform (STFT) which calculates the Fourier transform of a windowed part of the signal and shifts the window over the signal. The short time Fourier transform gives the time-frequency content of a signal with a constant frequency and time resolution due to the fixed window length. This is often not the most desired resolution. For low frequencies often a good frequency resolution is required over a good time resolution. For high frequencies, the time resolution is more important. A multi-resolution analysis becomes possible only by using wavelet analysis. The continuous wavelet transform is calculated analogous to the Fourier transform, by the convolution between the signal and analysis function and retrieves the time-frequency content information with an improved resolution compared to the STFT. However the trigonometric analysis functions are replaced by a wavelet function. The specialty with wavelets is that the wavelet is a short oscillating function which contains both the analysis function and the window. Time information is obtained by shifting the wavelet over the signal. The frequencies are changed by contraction and dilatation of the wavelet function.

In a two dimensional DWT, a single level decomposition on an image produces four bands of data, one corresponding to the low pass band (LL) and two others corresponding to mid frequency bands namely horizontal (HL), vertical (LH) and one

high pass band namely diagonal (HH). With single level wavelet decomposition, the area for embedding the watermark is maximized [11]. In general, watermarking done in low frequency band is more robust to image distortions that have low pass characteristics like filtering, geometric attacks and compression whereas watermarking done in high frequencies is robust to noise and non-linear attacks but less robust to filtering, compression and geometric deformations [11]. In this work, watermarking is done in the LL band to be robust to large classes of attacks including filtering, compression and collusion.

2.1 COLOR SPACE

Color transformation deals with processing the components of a color image within the context of a single color model as composed conversion of those components between models. In order to maintain a high degree of color consistency, the model of choice for many color management systems (CMS) is the CIE L*a*b* model also called as CIELAB. The advantage of L*a*b* color space is it's colorimetric, perceptually uniform and device independent nature. Also its gamut encompasses the entire visible spectrum and can represent accurately all the colors. L*a*b* color space decouples intensity and color making it useful in image manipulation applications [12]. Hence, in the proposed work, L*a*b* space is used for watermarking as it models human perception of colors. Since, it is not a directly displayable format; the watermarked image is converted back to RGB color space.

3. PROPOSED WATERMARKING APPROACHES - DWTC AND DWTLC

The proposed schemes need the following pre- processing steps explained below.

3.1 PRE-PROCESSING

With the proposed approaches, the pre- processing step includes color space conversion, encoding and scrambling the watermark.

Step 1: Color Space Conversion

Initially, the original image I of size N×N is converted to L*a*b* color space from RGB space. The reason for color space conversion in the proposed work is that the L*a*b* color model represents the human perception of colors more closely than the standard RGB model.

Step 2: Encoding

For the DWTC scheme, the color information in L*a*b* space is then coded as complex number Z of the form as proposed by Tsz Kin Tsui et al. [13]. This is shown in Eq. (2).

$$Z = a + jb \tag{2}$$

and for the DWTLC scheme, the luminance and the color information are coded as complex number Z of the form given by Eq. (3):

$$Z = (L + a) + jb \tag{3}$$

where L corresponds to the luminance ; a and b correspond to the chrominance content of the image in L*a*b* space.

Step 3: Scrambling the Watermark W_E

The watermark (WE) to be embedded is not a traditional one dimensional pseudo-random sequence but a logo. Any video, audio or image can be used as the watermark and it has to be converted to binary bit stream. In this work, the watermark is scrambled in order to improve the watermark's robustness. Even if an attacker detects the watermark signal, he cannot recover the original watermark without the scrambling algorithm. Thus, this scrambling strengthens the security and secrecy of the watermark.

The embedding and the extraction mechanisms for both WFWC and WFWLC schemes are one and the same and are discussed in the following section.

3.2 WATERMARK EMBEDDING

DWT is applied to the magnitude of the chrominance content of the original color image for DWTC as shown in Eq. (2) and to the magnitude of both the luminance and chrominance content of the color image as shown in Eq. (3) for DWTLC. A single level DWT decomposition produces four bands of data. To the wavelet transformed coefficients in the LL band, the scrambled watermark is embedded in random locations as guided by a function. Watermarking is done as shown in Eq. (4):

$$F(f_1, f_2) = \begin{cases} G(f_1, f_2) + \beta \bullet G(f_1, f_2) & \text{if } W(k) = 1 \\ G(f_1, f_2) - 1/\beta \bullet G(f_1, f_2) & \text{if } W(k) = 0 \end{cases} \tag{4}$$

where, $G(f_1,f_2)$ is any original wavelet transformed coefficient, $F(f_1,f_2)$ is the watermarked wavelet coefficient, β is the watermark strength, $W(k)$ is the logo and k is the index of the watermark to be embedded. Depending on the perceptual requirement, the value of β is varied. The original DWT coefficients in the LL band are replaced by the watermarked coefficients and inverse DWT is applied. Watermarked image IW is obtained by converting the resultant L*a*b* into RGB space. The watermark embedding framework is shown in Fig.2.

3.3 WATERMARK EXTRACTION

To extract the embedded watermark, the original image I and the watermarked image IW or the probably attacked images are needed. Both the images are then converted to L*a*b* space and encoded. The values of $G(f_1,f_2)+\beta.G(f_1,f_2)$ and $G(f_1,f_2) - 1/\beta \cdot G(f_1,f_2)$ are calculated from the original image on those locations determined by the random function. Then a distance comparison is made to the coefficients extracted from the watermarked image/ attacked image. The bit in the extracted watermark WX is '1' or '0' depending on how the coefficients extracted from the watermarked image are closer to those values computed from the original image. The scrambled watermark is reconstructed using the extracted watermark bits. The watermark extraction framework is shown in Fig.3.

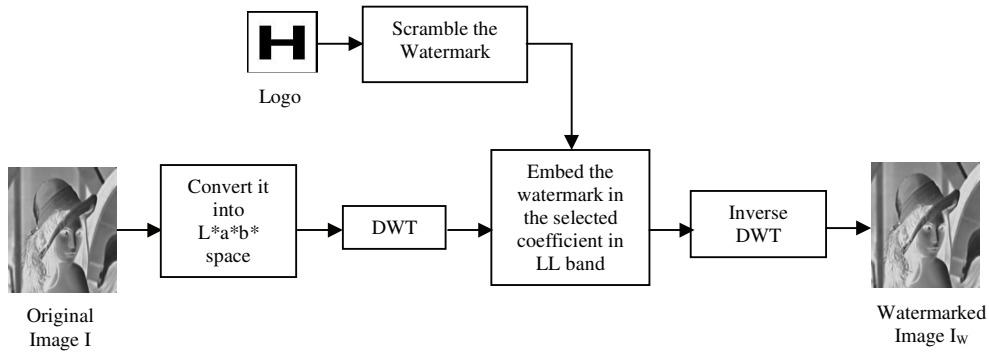


Fig.2. Watermark embedding using the proposed DWTC/DWTLC Watermarking

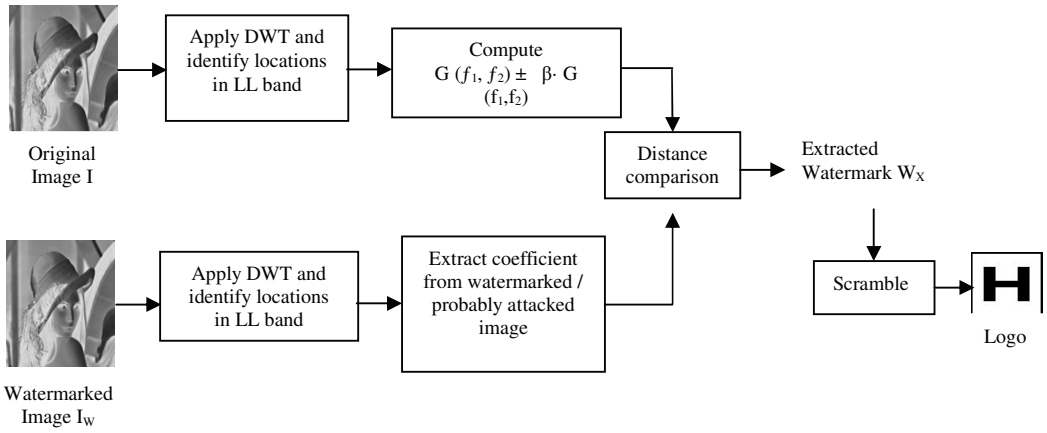


Fig.3. Watermark extraction using the proposed DWTC/DWTLC Watermarking

4. EXPERIMENTAL RESULTS

In this section, the effect of DWTC and DWTLC schemes implemented using MATLAB R2007b is presented. The fidelity criteria and robustness of the proposed watermarking schemes are evaluated with standard test images available in USC-SIPI image database [14] and those discussed in tables are shown in Fig.4. The proposed approaches are compared with an existing SCDFT based approach proposed by Tsz Kin Tsui et al. [13] and a DWT based approach proposed by Ramana et al [10]. In Tsz Kin Tsui et al. approach, watermarking is done on chrominance content. In Ramana et al. approach, watermarking is done on the mid frequency bands with a gain $\alpha = 0.6$.

In the experiments for the proposed schemes, an image of size 256×256 is subjected to a single level decomposition using Haar filter. This results in four bands of data and the LL band is chosen for embedding the watermark. Watermark to be embedded is a Logo. Experiments are conducted with many Logos each of different sizes and for readability sake only one is shown in Fig. 5 (b). This is scrambled first to be robust enough to attacks. The scrambled watermark is then embedded in the LL band in those coefficients decided by the random function using Eq. (4). The original and watermarked Lena images using DWTC and DWTLC approaches are shown in Fig.5 (c) and (d) along with associated PSNR.

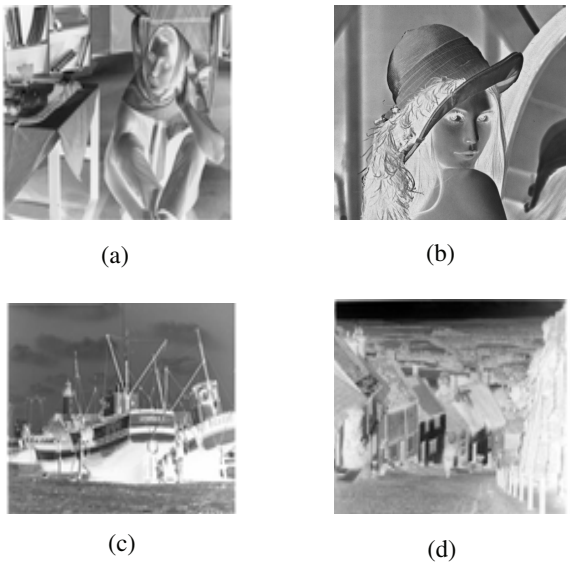
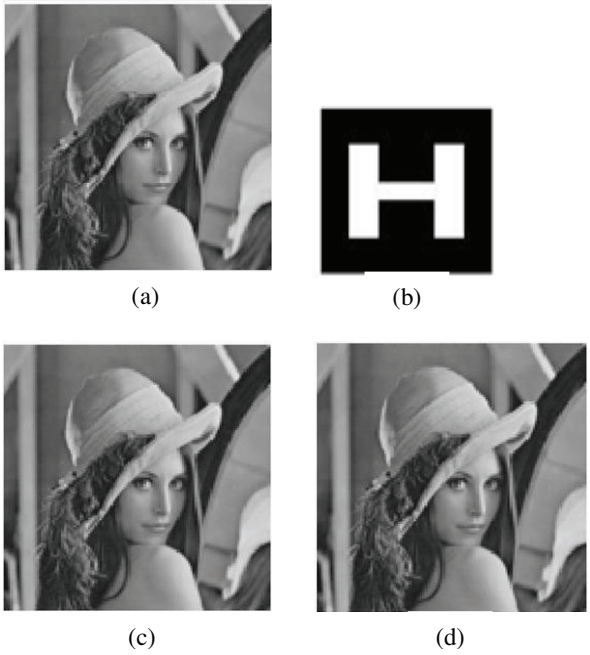


Fig.4. Test images used – (a) Barbara (b) Lena (c) Boats (d) Goldhill



(a) (b)

(c) (d)

Fig.5. (a) Original Image (b) Logo (c) and (d) Watermarked Images using DWTC with PSNR: 57.09dB and DWTLC with PSNR: 56.76dB respectively

An important parameter used in the embedding procedure is the value of β, which is the embedding strength that is fixed depending on the level of imperceptibility needed. In the experiments β value is chosen as $\beta = 0.02$. It is chosen after the conduct of experiments and its impact against PSNR is reported in Fig.6. From the figure, it is clear that the PSNR is good for values $\beta < 0.2$ and hence $\beta = 0.02$ is taken for further experiments.

In the rest of this section, first the Fidelity criteria of the proposed watermarking approaches are analyzed. Then, the robustness of the proposed watermarking approaches is shown by the conduct of various experiments. Next to that, comparison of the proposed approaches against existing SCDFT approach [13] and DWT approach [10] is discussed. Finally, the resistance of the proposed approaches against Collusion attack is discussed.

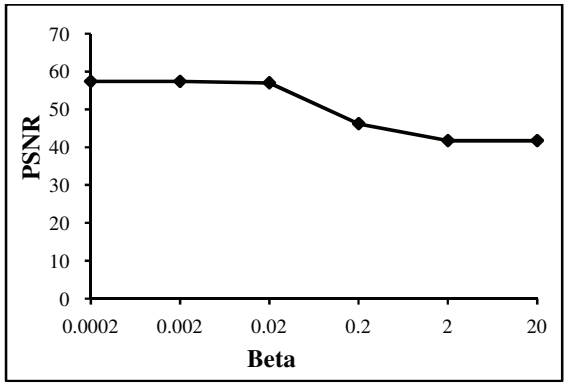


Fig.6. Impact of Beta vs. PSNR

4.1 FIDELITY CRITERIA

When the level of information loss is expressed as function of original image and watermarked image, then it is said to be based on objective fidelity criterion [12]. The root mean square error is one such best criteria and is given in Eq. (5).

$$RMSE = \sqrt{\frac{1}{w \times h} \sum_{j=0}^{h-1} \sum_{i=0}^{w-1} \left(\left(\Delta R_{ij} \right)^2 + \left(\Delta G_{ij} \right)^2 + \left(\Delta B_{ij} \right)^2 \right)} \quad (5)$$

where Rij, Gij and Bij are the red, green and blue values of the pixel and w and h are the width and height of the image.

Table.1. PSNR of the proposed schemes

Images	Dimension	PSNR	
		DWTC	DWTLC
Barbara	256×256	57.28	57.02
	512×512	57.55	57.57
Lena	256×256	57.09	56.76
	512×512	57.34	57.26
Boats	256×256	57.15	56.96
	512×512	57.46	57.39
Goldhill	256×256	56.92	56.64
	512×512	57.29	57.25

Table.2. BER for various attacks

Attack	Parameter	BER
Mean Filtering	3×3 mask	0
	5×5 mask	0
	7×7 mask	0
Median Filtering	3×3 mask	0
	5×5 mask	0
	7×7 mask	0
Average Filtering	3×3 mask	0
	5×5 mask	0
	7×7 mask	0
Weiner Filtering	3×3 mask	0
	5×5 mask	0
	7×7 mask	0
Blurring		0
Sharpening		0
Histogram Equalization		0
Intensity Adjustment		0
Decorrelation Stretch		0
JPEG Compression	Qf - 80	1.8
	Qf - 40	2.77
	Qf - 20	4.6
Scaling	sf - 1.5	0
	sf - 3	0
	sf - 5	0
Additive noise	v=1	0
	v=2	2.77
	v=3	4.33
	v=4	8.33

To evaluate the fidelity of the watermark, the peak signal to noise ratio is used and it is measured as in Eq. (6). The typical value for PSNR is between 30 and 50 dB and the higher, the

better. The proposed watermarking schemes are tested for various images and the PSNR obtained is shown in Table 1.

$$PSNR = 10\log_{10}\left(\frac{3\times 255^2}{RMSE}\right) \quad (6)$$

From Table 1, it can be seen that the PSNR of the watermarked images is very good with good visible quality irrespective of the image dimensions. This is shown in Fig. 5. It is observed that there is a slight increase in image quality while considering the chrominance alone for watermarking in the DWT domain.

4.2. ROBUSTNESS OF THE WATERMARK

In order to show the robustness of the proposed DWTC and DWTLC schemes against attacks, a series of experiments have been conducted by applying the attacks to watermarked Lena image of size 256×256. We consider both geometric and non geometric attacks. Non geometric attacks include JPEG compression, filtering, histogram equalization, sharpening, blurring, image intensity adjustment and decorrelation stretch. Geometric attacks include scaling, rotation and additive noise.

The test results indicate that the proposed watermarking schemes produce watermarked images with best quality and in addition to that, the watermark is resistant to various geometric attacks and common image processing operations. The robustness is illustrated with the given bit error rate (BER) which is defined as the ratio between the number of incorrectly extracted bits and the length of the watermark [15]. BER for various attacks conducted are listed in Table 2.

4.2.1. Non Geometric Attacks

Filtering - Images watermarked using proposed watermarking schemes are attacked by mean, median, average and Weiner filters with a mask of size 3×3, 5×5, 7×7. In all the cases, the watermark is recovered with zero BER. The recovered watermark after average filtering with a mask of size 7×7 is shown in Fig.7 (a). This robustness is achieved because the watermarking is done by modifying only selected coefficients in the approximation band and the watermark is embedded in a multiplicative way.

Blurring - Blurring in the fre0000quency domain refers to the suppression of high frequencies. Blurring attack is performed by image filtering that convolves a point spread function with the watermarked image to produce a blurred watermarked image. The proposed scheme resists blurring attack with zero BER and is shown in Fig.7 (b).

Sharpening - Both the proposed methods can resist sharpening strongly with zero BER over the whole range of intensity as shown in Figure 7(c).

Histogram Equalization - Histogram equalization is usually used for image enhancement. It is a kind of histogram modeling technique that modifies the dynamic range and contrast of an image so that its intensity histogram has a desired shape. The watermarked image is histogram equalized by making use of a nonlinear mapping that reassigns the intensity values so that the attacked image has a flat histogram. Figure 7 (d) shows the watermark recovered with zero BER after histogram equalization.

Image intensity adjustment - The watermarked image is attacked by intensity adjustment. Intensities between 0.2 × 256, 0.3 × 256 and 0×256 in each plane are mapped to intensities between 0.6×256, 0.7×256 and 1× 256. Though, the watermark is embedded in luminance and chrominance content, the proposed schemes are immune to image intensity adjustment with zero BER as shown in Fig.7 (e).

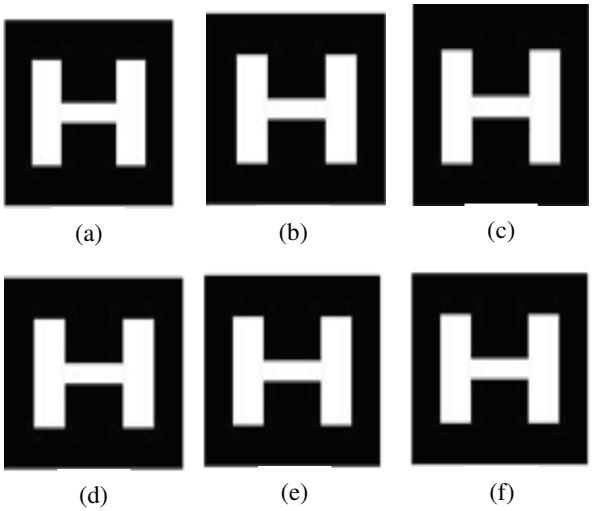


Fig.7. Watermarks recovered after the non geometrical attacks (a) Average filtering by a mask of size 7×7 (b) Blurring (c) Sharpening (d) Histogram Equalization (e) Intensity adjustment (f) Decorrelation stretch

Decorrelation Stretch - Decorrelation stretch attack as available in MATLAB enhances the color separation of an image with significant band-band correlation. The exaggerated colors improve visual interpretation and make feature discrimination easier. However, when this is applied to watermarked images, it does not affect the watermark recovery and it ensures zero BER as shown in Fig.7 (f).

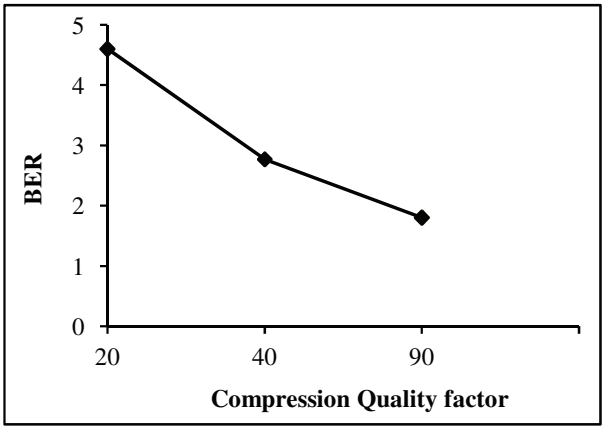


Fig.8. JPEG compression Quality factor (Qf) Vs. BER

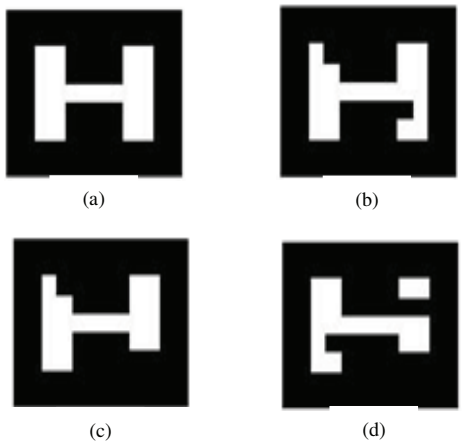


Fig.9. Watermarks recovered after JPEG Compression attacks – (a) Qf-80 (b) Qf-40 (c) Qf-30 (d) Qf-20

JPEG Compression - The watermarked images are compressed with both JPEG Lossy and Lossless Compression. With the case of lossless compression, the watermark is recovered perfectly with zero BER even when the quality factor (Qf) is varied from 90 to 10. But with lossy compression, the watermark is visible as long as the Qf is greater than 40. The results obtained for JPEG lossy compression is shown as a function of BER and compression quality in Fig.8. If the Qf is reduced further, there is slight disturbances in the recovered watermark and is shown in Fig.9.

4.2.2 Geometric Attacks

Scaling - For image scaling operations, the watermarked images are individually scaled by a factor (sf) of 1.5, 3 and 5 in each direction. Before watermark extraction, the watermarked image is rescaled back to its original size using bilinear interpolation because the proposed algorithm requires the pixels in the watermarked image to be in the corresponding location as the original host image in order to extract the watermark correctly. After scaling operations, the watermark embedded in the LL band is recovered successfully with zero BER from the scaled watermarked image and the watermarks recovered after scaling attacks with sf= 1.5, 3 and 5 are shown in Fig.10.

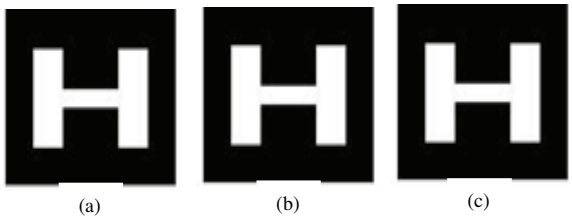


Fig.10. Watermarks recovered after scaling attacks (a) sf = 1.5 (b) sf = 3 (c) sf = 5

Rotation - Rotation attack is performed by rotating the watermarked image by a small angle, then scaling the rotated image and finally cropping the scaled image to the original image size. In a pixel based watermarking system, even if the image is rotated by a small degree, the positions of the pixels are shifted. Though, the rotation attack does not cause severe visual degradation it produces errors during watermark extraction.

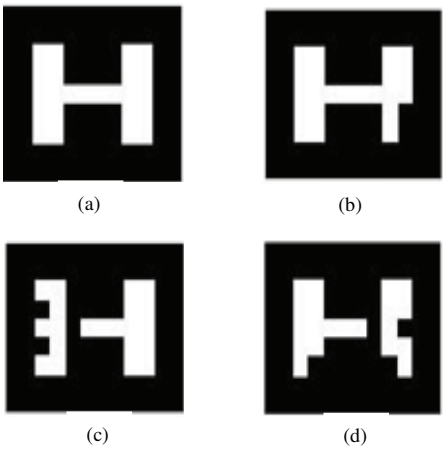


Fig.11. Watermarks recovered after additive noise for variance v (a) v=1 (b) v=2 (c) v=3 (d) v=4

Additive noise - The watermarked images are distorted by additive Gaussian noise with zero mean and a variance (v) which is varied from 1 to 4. The watermark is however recognizable as long as the variance is less than equal to 4 and this is shown in Fig.11. Beyond that, the proposed schemes can recover the watermark with much degradation. The BER obtained for the noise added with various levels of variances are shown in Fig.12.

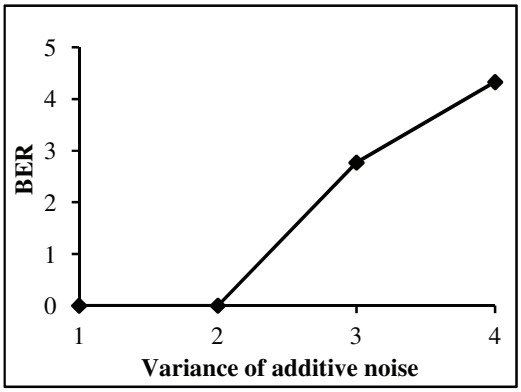


Fig.12. Impact of variance of additive noise Vs. BER

4.3 COMPARISON OF THE PROPOSED SCHEMES AGAINST SCDFT BASED APPROACH

The proposed schemes appear similar in the way the chrominance contents are utilized for watermarking in the SCDFT approach proposed by Tsz Kin Tsui et al. [13]. The use of wavelets for watermarking has considerably increased the PSNR of the watermarking approach to 57 dB on an average as shown in Table 1. But for the SCDFT approach when the Logo shown in Fig.5 (b) is embedded, the PSNR is between 40 and 45 dB. Also, the proposed approaches are resistant to scaling even by a factor of 5 whereas the SCDFT results in some errors during watermark recovery. Also, the SCDFT approach is not resistant to JPEG compression especially for a low compression factor. The proposed schemes on the other hand, guarantee

perfect extraction of the watermark when the quality factor is $40<Qf<90$and with minimal BER even when the quality factor is as low as 20. This is shown in Fig.9.

4.4 COMPARISON OF THE PROPOSED SCHEMES AGAINST DWT BASED APPROACH

The DWT based approach proposed by Ramana et al. [10] shows resistance to additive noise and salt and pepper noise only for a small variance. But the proposed schemes can resist additive noise even when the variance is 4. All the other attacks on the DWT scheme do not guarantee the recovery of the embedded watermark. Also, the PSNR of the watermarked images using this DWT approach is on an average 42 dB. On the other hand, the proposed schemes are resistant to a variety of attacks as discussed earlier with a PSNR of 57 dB on an average.

4.5 RESISTANCE TO COLLUSION ATTACK

Conventional watermarking techniques are concerned with robustness against a variety of attacks such as filtering but do not always address robustness to attacks mounted by a coalition of users with the same content that contains different marks. These attacks, which are known as collusion attacks, can provide a cost effective approach to removing watermark. Linear collusion is one of the most feasible collusion attacks against watermarking. When users come together with a total of K differently watermarked copies of the same multimedia content, these users can simply linearly combine the K signals to produce a colluded version. Since normally no colluder is willing to take more of a risk than any other colluder, the watermarked signals are usually averaged with an equal weight for each user. This averaging reduces the power of each contributing watermark. As the number of colluders increases, the embedded watermark becomes weaker. In fact, the colluded signal can have better perceptual quality in that it can be more similar to the host signal than the watermarked image.

(a)

(b)

(c)

(d)

Fig.13. Colluded Lena images – (a) with β=0.2 for 5 users (b) with β=0.2 for 2 users (c) with β=0.02 for 5 users (d) with β=0.02 for 2 users

With the proposed approaches, as the geometry of each copy is distorted independently (embedding is done in LL band at randomly chosen coefficients), a collusion attack yields a low quality signal. According to Tanmoy Kanti Das et al. [16], for an

image of size 256 ×256 or 512× 512, for a successful collusion attack, a large number of watermarked images may be required, depending on the size of the key information. They also state that this is not practical. But it is not true with our schemes. We show that collusion even with only two copies results in disturbing distortions as shown in Fig.13 by marked area and visual quality does not improve when the number of copies is increased. More degradation encounters with increased number of colluders as shown in Fig.13 (a) and (c) where collusion is done with 5 users. High quality colluded image can be obtained only with special software and with substantial computational resources, but this is not feasible. Also, it is observed from our previous work that the embedding strength β has an impact on the collusion strength [17]. Hence, in the proposed work the embedding strength is increased further and is seen that an increase in β from 0.02 to 0.2 produces disturbing distortions in the visual quality of the colluded images as shown in Fig.13 for collusion with 2 users and 5 users.

5. CONCLUSION

In this paper, we have proposed non-blind watermarking schemes that utilize the luminance and chrominance contents for watermarking in the L*a*b* space. It is based on DWT and the watermark is scrambled before embedding. Watermarking is done on the approximation band on selected coefficients decided by the random function. As a result, the watermark is robust to a wide variety of attacks. In the proposed schemes, the PSNRs of the watermarked images are on an average 57dB. The schemes can effectively resist common image processing attacks especially JPEG compression (with a quality factor up to 20), filtering (mean, median, average and Weiner) by a mask of size 3×3, 5×5 and 7×7, blurring, sharpening, histogram equalization and intensity adjustment. Also, it is resistant to geometric attacks like scaling and Gaussian noise with a variance less than 4. After undergoing all these attacks, the extracted watermark is still recognizable. The scheme is superior in the way it resists collusion attacks. The watermark embedding strength and the location is shown to have an impact on the resistance of the proposed schemes to collusion attacks. Also, the scheme can resist collusion even for a minimum of two colluders and with increasing number of colluders, there is much distortion in the visual quality. Both DWTC and DWTLC schemes find their application in image authentication, copy control and content tracking. Future work is to concentrate on the attacks like color grayscale conversion, cropping that have not been considered yet.

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