Color Image Watermarking using JND Sampling Technique

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Abstract

This paper presents a color image watermarking scheme using Just Noticeable Difference (JND) Sampling Technique in spatial domain. The nonlinear JND Sampling technique is based on physiological capabilities and limitations of human vision. The quantization levels have been computed using the technique for each of the basic colors R, G and B respectively for sampling color images. A watermark is scaled to half JND image and is added to the JND sampled image at known spatial position. For transmission of the image over a channel, the watermarked image has been represented using Reduced Biquaternion (RB) numbers. The original image and the watermark are retrieved using the proposed algorithms. The detection and retrieval techniques presented in this paper have been quantitatively benchmarked with a few contemporary algorithms using MSE and PSNR. The proposed algorithms outperform most of them.

Keywords: Color image watermarking, JND sampling, Reduced Biquaternion, Retrieval

1. Introduction

Digital watermarking is a technique to embed secret information in videos or images. Color image watermarking is a comparatively unexplored field relative to gray-level image watermarking. The watermarking algorithms can be either spatial domain or transform domain. Most of the watermarking schemes exploit limitations of the human vision i.e. the human eye sensitivity to the light spectrum, discrimination power for discriminating the colors etc. The sensitivity of Red color vision is the lowest, though it fascinates or attracts the most. The sensitivity of Green color vision is the highest. The Blue vision is moderately sensitive. Kutter, *et. al.* (1997) have used the blue channel of the RGB space for embedding the watermark as the human eye is moderately sensitive to blue color. The embedding process uses spread spectrum techniques in the frequency domain and then transforms it to spatial domain. Most of the existing algorithms mark the channels of color separately, without considering the correlation of the image or watermark color components. Reed & Hannigan (2002) proposed a system that takes advantage of the low sensitivity of the human visual system to high frequency changes along yellow-blue axis to place most of the watermark information in yellow component of the image in CMY space. The quality of watermarking should be such that it is not detected by the human eye or the sensitivity of vision to the light spectrum is very important while evaluating the quality of watermarking as presented as by Piva *et. al.* (1999). In this scheme, the embedding process is an additive (spread-spectrum) scheme in the DCT domain. The Lab color space decomposition presents interesting properties in the watermarking context and the same is used (Fleet and Heeger 1997). A watermarking scheme based on the QFT and the Quantization Index Modulation scheme is presented by Bas *et. al.* (2003). In this method, imperceptibility is emphasized but the robustness to extensive attacks is overlooked. Watermarking scheme for color images based on local quaternion Fourier spectral analysis (LQFSA) has been discussed in Xiaojun *et. al.* (2008). It uses Quaternion Fourier transform defined in a 4D vector space which provides a larger embedding scope for watermark than conventional monochannel transformation techniques. The LQFSA technique provides improved perceptibility of watermark with regard to human color vision properties after reconstruction. Tsui *et. al.* (2006) proposed a new quaternion based watermarking. It interprets the QFT coefficients using spatio-chromatic Fourier analysis. In this work, robustness and invisibility is balanced by modifying both positive and negative coefficients and this scheme deals only with most common attacks.

The JND sampling technique has been used in various Image Processing applications such as color image segmentation (Ray & Bhurchandi 2000), content based image retrieval (Bhoyar & Kakde 2007), printing of color images on white background (Bhurchandi *et.al.* 2010) etc. In this paper, we have presented a color watermarking technique in spatial domain using JND sampling technique in all the three channels or planes of a color image. We have used JND sampled color images and 1/2 JND scaled watermark for watermarking. In many papers (Kutter *et. al.* 1997; Reed & Hannigan 2002; Piva *et. al.* 1999; Fleet & Heeger 1997; Bas *et. al*. 2003; Xiaojun *et. al.* 2008), the quaternions and Reduced Biquaternion are mainly used for watermarking of the color images. We have used RB to represent the watermarked image. The representation of the watermarked image in RB form adds another level of encryption and is used for transmission over a channel. Use of Reduced Biquaternions in the field of image applications is relatively new and has a wide scope of research.

Rest of the paper is organized as follows. In section 2 we have discussed the JND sampling technique in brief. Definition of Reduced Biquaternions, its representation in matrix and polar form has been presented in section 3. Representation of watermark using half JND value, embedding technique and Retrieval of watermark has been presented in section 4. Finally, results have been presented in section 5 along with subsequent benchmarking followed by conclusion.

2. JND Sampling Technique

The incremental behavior of human retina has been modeled by Buchsbaum using a differential equation (Buschbaum 1980, 1981). The non-linearity of human vision on R, G and B axes was proposed by Buchsbaum (1981) as in eq. (1).

$$y(I) = \frac{K}{4q - p^2}\left[\tan^{-1}\frac{2qI + p}{\sqrt{4q - p^2}}\right]^2 + C \qquad (1)$$

where, *K* represents gain, *p* and *q* represents illumination constant in the two directions, *I* is input intensity, *C* represents saturation of the eye and *y(I)* is output of the system which can be expressed in terms of JND colors on R, G and B axes respectively. These quantization levels (JNDs) can be calculated solving eq. (1) as in eq. (2).

$$I = \frac{\sqrt{4q - p^2}}{2q} * \tan\sqrt{\frac{(y - C)\sqrt{4q + p^2}}{K}} - \frac{p}{2q} \qquad (2)$$

An experiment has been carried out to model the just noticeable different (JND) color response of a certified sound color normal eye to the varying color intensities using 64 color palettes of each basic color under daylight illumination conditions over an average gray background by Raut & Bhurchandi (2008). This response is further used to evaluate the parameters of the visual non-linearity; *p*, *q*, *K* and *C* using a neural network curve fitting procedure with an error of less than one JND for daylight illumination.

In the proposed approach of sampling color images, using the above parameters in eq.(1), the *y(I)* quantization levels on each axes have been computed and every pixel color in the image has been reduced to its nearest lower *y(I)* level. The 24, 28 and 26 JND values have been computed for each of the R, G and B basic colors (Raut & Bhurchandi 2008). It is to be noted that the JND values for each of these basic colors are in the range 0-255. For the proposed watermarking technique, the image to be watermarked is sampled using the JND values in the range 0 to (255-0.5*JND) to restrict the R/G/B value to 255 after water marking i.e. adding the watermark image. This sampling results in little distortion in the original image it is not noticeable as it is within one JND range. The water mark logo image is scaled to 0.5*JND and added to the sampled image but this also does not affect the visual appearance of the image as all the changes are within one JND. However the sampling process may add a very small distortion in some other areas of the image excluding the watermark embedding position. The resulted distortion may misguide the hacker who would try to attack the watermarked image.

3. Hypercomplex Numbers

In this section we discuss theory of quaternions in brief.

3.1 A Quaternion

The well known concept of quaternions was introduced by Hamilton in 1843 (Hamilton 1979; Kantor & Solodovnikov 1989; Soo-Chang Pei *et. al.* 2004). It has been used for color image processing by many researchers (Kutter *et. al.* 1997; Reed & Hannigan 2002; Piva *et. al.* 1999; Fleet & Heeger 1997; Bas *et. al*. 2003; Xiaojun *et. al.* 2008; Tsui *et. al.* 2006). Quaternions are one of the generalizations of complex numbers. A complex number has one real part and complex part. A quaternion, however, has a real part and three imaginary parts and it can be represented in Cartesian form as in eq. (3).

$$q = a + ib + jc + kd \qquad (3)$$

where *a*, *b*, *c* and *d* are real numbers, and *i, j* and *k* are orthogonal complex operators (generalizations of the complex operator denoted by i among mathematicians and by j among electrical engineers). The properties of the three operators are as follows:

$$\begin{array}{llllllll} i^2 & = & j^2 & = & k^2 & = & ijk & = -1 \\ ij & = & k & jk & = & i & ki & = j \\ ji & = & -k & kj & = & -i & ik & = -j \end{array} \qquad (4)$$

Given a quaternion $q = a+ib+jc+kd$, its quaternion conjugate is $q^2 = a\text{-}ib\text{-}\ jc\text{-}\ kd$, and its modulus is given by:

$$|q| = \sqrt{a^2 + b^2 + c^2 + d^2} \qquad (5)$$

Multiplication of quaternions is *not commutative,* and there are left and right quotients from division. This has profound ramifications in that, for example:

$$e^{ib + jc} \neq e^{ib}\ e^{jc} \qquad (6)$$

The fundamental reason for the non-commutativity of quaternion multiplication is that it involves a vector cross-product whose direction (in 4-space in this case) is reversed by interchanging the operands. This problem restricts the applications of quaternions in signal and image processing.

3.2 Reduced Biquaternion

In 1864, Hamilton originally proposed Biquaternion. These biquaternions, with eight elements, are not commutative in multiplication, and do not form a division algebra. This limitation is overcome by Reduced Biquaternion which was proposed by Schtte and wenzel (1990). Reduced Biquaternions belong to the class of hypercomplex algebra. The representation of RBs is presented by Schtte and wenzel (1990) and is given by eq. (7)

$$q = q_r + q_i\, i + q_j\, j + q_k\, k \qquad (7)$$

$$\begin{aligned} where,\ & ij = jk = k, \quad jk = kj = i \\ & ik = ki = -j, \quad i^2 = k^2 = -1, \quad j^2 = 1 \end{aligned} \qquad (8)$$

From eq. (8) we can find the multiplication rule of RBs is commutative. This is the unique advantage over quaternions. This makes implementation of Discrete Reduced Biquaternion Fourier Transform (DRBFT) much simpler than the existing implementation of quaternions.

$$\begin{aligned} q &= q_r + q_i + q_j + q_k \qquad is \\ q &= q_r + q_i \cdot i + q_j \cdot j + q_k \cdot k \end{aligned}$$

$$\rightarrow Mq = \begin{bmatrix} qr & -qi & qj & -qk \\ qi & qr & qk & qj \\ qj & -qk & qr & -qi \\ qk & qj & qi & qr \end{bmatrix} \qquad (9)$$

And the determinant of Mq, δ is given in (10).

$$\delta = \begin{vmatrix} qr & -qi & qj & -qk \\ qi & qr & qk & qj \\ qj & -qk & qr & -qi \\ qk & qj & qi & qr \end{vmatrix} \geq 0 \qquad (10)$$

The polar form of these RB components can be represented with δ (determinant of q) $\neq 0$ as in (11).

$$q = a + bi + cj + dk = Ae^{i\theta_i} e^{j\theta_j} e^{k\theta_k} \qquad (11)$$

$$where, \quad A = |q| = \sqrt[4]{\delta} \geq 0, \theta_i \in (-\pi, \pi), \theta_k \in (-\pi/2, \pi/2), \theta_j \in R$$

3.3 Color Image Representation using RB

To represent the sampled image in RB, we are using the real part of RB to represent R component of the image. *i* and k imaginary parts hold B and G component respectively. *j* component is ignored in this case. Thus, the color image is represented as in (12):

$$f_{RB}(x,y) = f_R(x,y)\, e^{if_G(x,y)} e^{kf_B(x,y)} \qquad (12)$$

For processing, the image is then represented in matrix form of RB using equation (13)-(15).

$$e^{i\theta i} \leftrightarrow M_{\theta i} = \begin{bmatrix} \cos\theta i & -\sin\theta i & 0 & 0 \\ \sin\theta i & \cos\theta i & 0 & 0 \\ 0 & 0 & \cos\theta i & -\sin\theta i \\ 0 & 0 & \sin\theta i & \cos\theta i \end{bmatrix} \qquad (13)$$

$$e^{i\theta j} \leftrightarrow M_{\theta j} = \begin{bmatrix} \cosh\theta j & 0 & \sinh\theta j & 0 \\ 0 & \cosh\theta j & 0 & \sinh\theta j \\ \sinh\theta j & 0 & \cosh\theta j & 0 \\ 0 & \sinh\theta j & 0 & \cosh\theta j \end{bmatrix} \qquad (14)$$

$$e^{i\theta k} \leftrightarrow M_{\theta k} = \begin{bmatrix} \cos\theta k & 0 & 0 & -\sin\theta k \\ 0 & \cos\theta k & \sin\theta k & 0 \\ 0 & -\sin\theta k & \cos\theta k & 0 \\ \sin\theta k & 0 & 0 & \cos\theta k \end{bmatrix} \qquad (15)$$

4. Watermarking Scheme

In this section, we discuss the different steps of the proposed watermarking algorithms using JND sampling techniques in spatial domain.

4.1 Watermark Embedding Technique

To develop an efficient image watermarking technique, selection of image *I(m, n)* to be watermarked is the key issue. For this scheme we recommend images with dark colors. The carrier image is sampled using the sampling technique. The watermark logo image *f(x, y)*, has been normalized to the range [0 1] and then scaled to 0 to 0.5*JND intensity values. A block of size *(x, y)* of the JND sampled carrier image, *I(x, y)* has been selected to add the watermark in it and obtain the watermarked image portion *W(x y)* as in eq.(16).

$$W(x, y) = I(x, y) + f(x, y) \quad (16)$$

W(x, y) is placed back at the original position of *I(x, y)* to achieve the water marked image. The watermarked image has been further encoded using Reduced Biquaternions. The image is represented in RB form using eq. (13)-(15) presented in section 3. The water marked image can thus be transported in this watermarked RB form. The RB representation offers one more level of encryption during transmission of the watermarked image. Fig. 1 below presents the watermark embedding process.

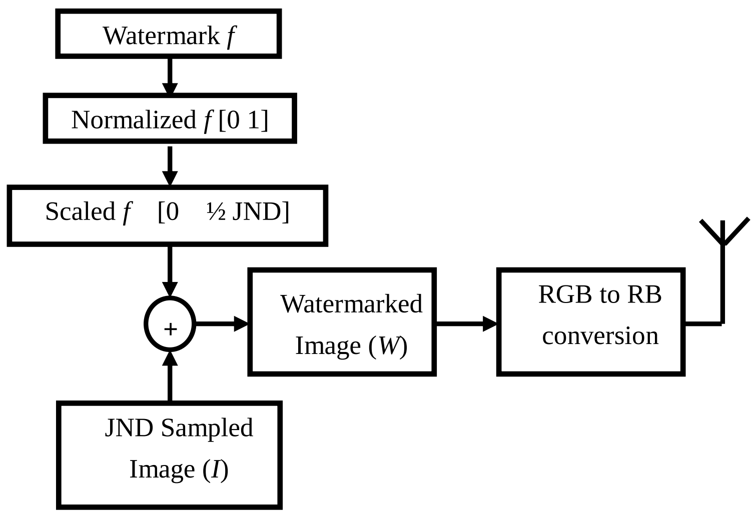


Fig. 1 Proposed system for embedding a watermark

4.2 Watermark Retrieval

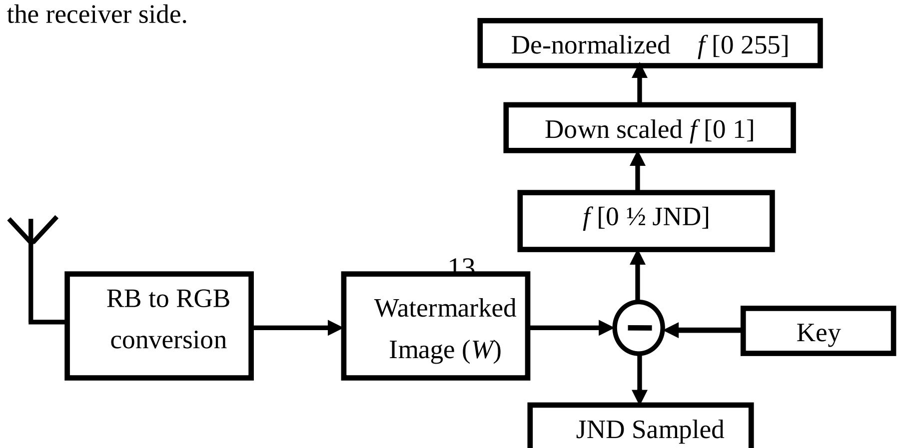
Initially, the RB form of the watermarked image is converted back to RGB image. The water marked RB image can be converted to its original form (R, G and B) using eq. (17)-(19) [9].

$$R = \frac{q_k}{\sin B \times \cos G} \quad (17)$$

$$G = \tan^{-1} \frac{q_i}{q_r} \quad (18)$$

$$B = \tan^{-1} \frac{q_k}{q_r} \quad (19)$$

The JND sampled image, *I(m, n)* and the watermark, *f(x, y)* can be retrieved from the watermarked image as shown in Fig 2 using the key. A key is supplied to the receiver for retrieving the carrier image and the watermark. The key consist of logo size, xy-coordinates of the embedding position in the carrier image, minimum and, maximum values of the R, G and B planes of the watermark. The key also has the JND quantization levels used to sample the carrier image. The quantization levels also can be supplied in advance to the receiver side.



5. Results

For benchmarking the proposed technique with others, selected logo shown in Fig. 3 was embedded in Fig. 4 and Fig 5. The reconstructed logo from the water marked image is shown in Fig 3(a). The Fig. 4(a),(b) and (c) show the respective sampled, water marked and retrieved carrier images. Similarly, the Fig. 5(a),(b) and (c) show the respective sampled, water marked and retrieved carrier images for carrier image shown in Fig. 5. Dark color carrier images have been selected for the experiments. The watermark in Fig. 6 has been embedded in the carrier images shown in Fig. 7 and Fig. 8. The reconstructed logo from the watermarked image is shown in Fig 6(a). The Fig. 7(a),(b) and (c) show the respective sampled, water marked and retrieved carrier images for carrier image Fig. 7. Similarly, the Fig. 8(a), (b) and (c) show the respective sampled, water marked and retrieved carrier images for carrier image shown in Fig. 8. It may be noted that proposed sampling technique results in little distortion in the original image but neither it is noticeable nor does it affect the embedding or retrieval of the watermark to or from the watermarked image. In fact the resulting distortion may be used to misguide the hacker, who would try to attack the watermarked image. The images have been represented in RB form before transmission. Table.1 shows the MSE values for the original images and retrieved images. The reconstruction using the proposed method is much better as compared to the Quaternion Fourier transform (QFT) and Discrete cosine transform (DCT) techniques as presented in Table 1. The MSE values after the specified attacks in Table 2. show that the algorithm is more robust than QFT and DCT. The RB reconstructed images have higher MSE (by around 10), but the retrieval is still much acceptable.

Table 1. MSE of Reconstructed water mark

Image	DCT	QFT	The Proposed Method	
			Watermark	Image
Pears	25.67	19.66	1.8	0.45
House	22.26	18.11	1.9	0.6
Rafting	21.22	17.9	1.6	0.9
Boat	23.19	18.01	1.7	1.3
Kodim17	23.96	17..99	2.0	1.1

Table 2. MSE for Robustness to Attacks

Attack	DCT	QFT	The Proposed Method	
			Watermark	Image
Histogram Equalization	28.13	25.61	6.71	2.6
Gaussian Noise (10%)	26.32	23.4	5.61	5.69
Average filter (3x3)	27.08	21.2	8.97	9.32
Median filter (3x3)	26.91	22.3	3.2	2.6

6. Conclusion

The proposed water marking scheme using JND Sampling offers retrieval of the water mark with minimum MSE as compared to other techniques. The Reduced Biquaternion representation is used to offer one more level of encryption to the watermarked image for transmission over a channel. Further addition in Fourier domain can be used for embedding watermark in sampled images in Frequency domain. More complex computational techniques increase the MSE during retrieval of the watermark. Pixel intensity values are being processed without dissociating from each other and this facilitates better retrieval of the color water mark.

Fig. 3 Watermark

Fig.3(a)Retrieved Watermark

Fig. 6 Original Watermark

Fig.6(a) Retrieved Watermark

Fig.4 Pears

Fig.4(a) Sampled Pears

Fig.7 Rafting

Fig. 7(a) Sampled Rafting

Fig. 4(b) Watermarked Pears

Fig. 4(c) Retrieved Pears

Fig. 7(b) Watermarked Rafting

Fig. 7(c) Retrieved Rafting

Fig.5 House

Fig.5(a) Sampled House

Fig. 8 Boat

Fig. 8(a) Sampled Boat

Fig.5(b)Watermarked House

Fig. 5(c) Retrieved House

Fig. 8(b)Watermarked Boat

Fig. 8(c) Retrieved Boat

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