Color Image Watermarking by Fibonacci Lattice Index Modulation

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Abstract

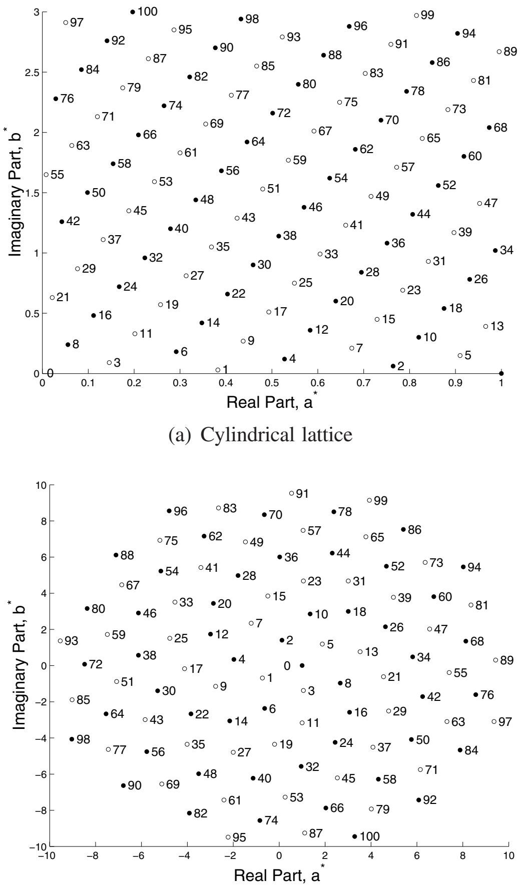
The intention of this paper is to specifically propose a color image watermarking method, instead of intuitively applying the watermarking approaches designed for gray-level images to the tri-channel signals of the color host images. Inheriting the good visual quality of the Fibonacci lattice applied in color quantization, the proposed method deploys the Fibonacci lattice points on the chromatic plane, and the fragile watermark message can be thereby embedded by modulating the indexes of lattice points unobtrusively. With another robust watermark embedded into the luminance component by the QIM approach, the hybrid watermarking system embeds two watermark messages with different purposes concurrently, and can thus be applied to various scenarios. Simulation results have shown that the fragile watermark embedded in the chromatic component does not degrade the function of the robust watermark embedded in the luminance component. Moreover, it performs a good capability of authentication, which is able to locate the slight modifications on the watermarked image.

Introduction

The speedy progress in information technology makes the exchange and spread of digital multimedia content more easily than before, yet challenges the copyright protection and authentication of creative works. Watermarking techniques are thereby extensively discussed with the aim to address these issues and provide the DRM (Digital Rights Management) with a firm basis. However, most digital images spread over the internet are color images, whereas most of the watermarking approaches are proposed for the host images in gray-level. Many color image watermarking methods intuitively apply the methods designed for gray-level images to the tri-channel signals of the color host images [1] [2] [3], where the inter-correlations among the tri-channel signals are disregarded. The intention of this paper is to present a novel image watermarking approach specifically proposed for color host images, where the color characteristics are taken into consideration.

The Fibonacci lattice has been applied to color quantization and shown to be comparable to other approaches for its good visual quality and the simplicity of color palette generation at decoder end [4]. Accordingly, the approach presented herein deploys the Fibonacci lattice points on the chromatic plane and embeds the watermark message by modulating the indexes. Inheriting the good visual quality in color quantization, the proposed approach unobtrusively embeds a *fragile* watermark into the chromatic component of the host image for the purpose of authentication. With another *robust* watermark embedded into the luminance component by the QIM approach [5], the hybrid watermarking system embeds two watermark messages with different purposes concurrently, and can thus be applied to a variety of scenarios. The so-called *fragile* watermark usually emphasizes its transparency property and is applied to content authentication which is expected to detect the modification of the host image. On the contrary, the *robust* watermark usually puts the accent on the robustness performance which is expected to resist the malicious elimination of the embedded watermark.

Fibonacci Lattice Index Modulation (FLIM)



(a) Cylindrical lattice

(b) Fibonacci lattice

Figure 1: Points of the Cylindrical and Fibonacci lattices in the complex plane.

The color quantization based on the Fibonacci lattice has been proven to be comparable to other approaches for its good visual quality [4] [6]. Each color pixel can thus be represented by an index which indicates the closest color in the palette. In addition, instead of transmitting the color palette at the encoder end, only few parameters are required to generate the color palette at the decoder end, namely a universal (image-independent) color palette.

The Fibonacci lattice is based on the *phyllotaxy* which is a special case of two-dimensional crystallography. The term *phyllotaxy* designates the geometry governing the plant pattern [6]. In [6], a *cylindrical lattice* can be defined in the complex Euclidean plane:

$$\Omega_c = \{\omega_c(n,m) \mid \omega_c(n,m) = (-\alpha + j\beta)n + m,\ m,n \in \mathbb{Z}\}\ , \quad (1)$$

where α and β are arbitrary real numbers. If $0 \le Re\{\omega_c(n,m)\} < 1$, then $m = \lceil \alpha n \rceil$, such that each point can be indexed only by n. Figure 1(a) shows the cylindrical lattice for $\alpha = (1+\sqrt{5})/2$ and $\beta = 0.03$. Please note that a sequence of continuous points on a straight line, as shown in Fig. 1(a) are numbered as an arithmetic progression whose increment is equal to one element of Fibonacci sequence. In [6], a spiral lattice is defined as the conformal transformation of a cylindrical lattice,

$$\Omega_s = \left\{ \omega_s(n,m) \mid \omega_s(n,m) = e^{-j2\pi\omega_c(n,m)} \right\}\ . \quad (2)$$

However, to have a uniform sampling in $L^*a^*b^*$ color space, Mojsilović *et al.* [4] modified Eq. (2) to define the *Fibonacci lattice*:

$$\Omega_F = \left\{ \omega_F(n) \mid \omega_F(n) = n^{\delta} e^{j2\pi n\tau},\ \ \tau,\delta \in \mathbb{R},\ \ n \in \mathbb{Z} \right\}\ . \quad (3)$$

Figure 1(b) shows the Fibonacci lattice in complex plane for $\delta = 0.5$ and $\tau = (1+\sqrt{5})/2$. In [4], the authors use the Fibonacci lattice to uniformly sample the $L^*a^*b^*$ color space, and to quantize the colors to the lattice points.

Inheriting the good visual quality in color quantization, the proposed FLIM approach accordingly deploys the Fibonacci lattice on the chromatic plane of $L^*a^*b^*$ color space. On that plane, lattice points are uniformly spread over, and each point is indexed by an integer number while the lattice point is generated. To construct the Fibonacci lattice on the a^*b^* plane for watermarking, the color host image should be converted to $L^*a^*b^*$ color space. The RGB signals of the host image are first converted to CIE (*Commission Internationale de l'Éclairage*) XYZ system by [7]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4902 & 0.3099 & 0.1999 \\ 0.1770 & 0.8123 & 0.0107 \\ 0.0000 & 0.0101 & 0.9899 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}\ . \quad (4)$$

Then, the values of XYZ system are converted to CIE 1976 $L^*a^*b^*$ system by [8]:

$$\begin{aligned} L^* &= \begin{cases} 116\left(\dfrac{Y}{Y_0}\right)^{\frac{1}{3}} - 16, & \dfrac{Y}{Y_0} > 0.008856 \\ 903.3\dfrac{Y}{Y_0}, & \dfrac{Y}{Y_0} \le 0.008856 \end{cases}\ , \\ a^* &= 500\left[f\left(\frac{X}{X_0}\right) - f\left(\frac{Y}{Y_0}\right) \right]\ , \\ b^* &= 200\left[f\left(\frac{Y}{Y_0}\right) - f\left(\frac{Z}{Z_0}\right) \right]\ , \end{aligned} \quad (5)$$

where

$$f(\lambda) = \begin{cases} \lambda^{\frac{1}{3}}, & \lambda > 0.008856 \\ 7.787\lambda + 0.1379, & \lambda \le 0.008856 \end{cases}\ ,$$

and X_0, Y_0, and Z_0 are the XYZ values of the reference white, which is typically the white of a perfectly reflecting diffuser under CIE standard D65 illumination [9]:

$$\begin{cases} X_0 = 0.950456 \\ Y_0 = 1 \\ Z_0 = 1.089058 \end{cases}\ .$$

Let x_a and x_b be the a^* and b^* values of a pixel, respectively, the point $X = x_a + j \cdot x_b$ in the complex plane can thus represent the chromatic component of this color. Similar to Eq. (3), a Fibonacci lattice for watermark embedding then comprises of the points:

$$\Omega_F = \left\{ \omega_F(n) \mid \omega_F(n) = s \cdot n^{\delta} e^{j2\pi n\tau} + \omega_0,\ \ 0 \le n \le n_{\max} \right\}\ , \quad (6)$$

where s is the scaling factor determining the Euclidean distance between of the neighbor points on a^*b^* plane, and thus affects the embedding induced distortion. The ω_0 is the centroid of the region which all the points X_i of the host image spread over. The $n_{\max}$ is set to ensure the distribution of Fibonacci lattice points covers the region in which all of X_i are enclosed. Therefore,

$$n_{\max} = \left\lceil \left(\frac{\max_i |X_i - \omega_0|}{s} \right)^{\frac{1}{\delta}} \right\rceil\ . \quad (7)$$

It should be noted that, in [4], the Fibonacci lattice points spirally encircle the origin of a^*b^* plane, and the radius increases as n increases, that is, $\omega_F(0) = 0 + j\,0$. However, the X_i of the host image may not distribute in the (a^*, b^*) region in which the origin is the center. This will cause the $n_{\max}$ to be large in vain and the computation time for searching will thus increase as well. In Eq. (6), the Fibonacci lattice points spirally extend from the centroid of X_i as $n = 0$, that is, $\omega_F(0) = \omega_0$. It will be more efficient and suitable for embedding or quantizing than the lattice points in Eq. (3). Figure 2(b) shows the distribution of a^*b^* points X_i of image "fruit" as shown in Fig. 2(a), and its corresponding Fibonacci lattice. Clearly, the distribution of chromatic points X_i in the a^*b^* plane is properly enclosed in the region of the Fibonacci lattice.

As shown in Fig. 1(b), it is noted that every lattice point of even index is surrounded by the points which at least one lattice point of odd index is included in, and vice versa. This signifies that two quantizers Q_0 and Q_1, which consist of the lattice points of even indexes and odd indexes, can be used to embed message bit "0" and "1", respectively,

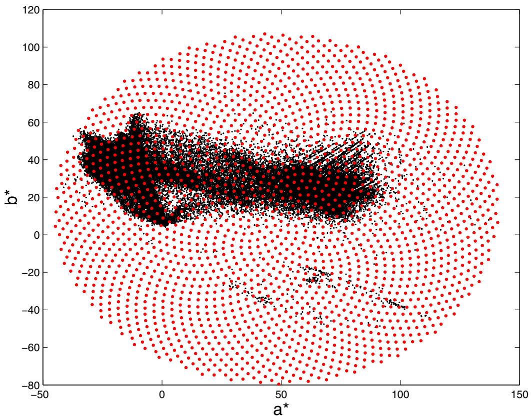
$$\begin{cases} Q_0 = \{\omega_F(n) \mid \mathrm{mod}(n,2) = 0,\ \ n \in \mathbb{Z}\} \\ Q_1 = \{\omega_F(n) \mid \mathrm{mod}(n,2) = 1,\ \ n \in \mathbb{Z}\} \end{cases}\ . \quad (8)$$

Namely, if a pixel of chromatic point X_i on the a^*b^* plane is expected to convey a watermark message bit "0" ($w_i = 0$), the quantized chromatic point $\tilde{X}_i$ is thus determined by the nearest Fibonacci lattice point of quantizer Q_0, whereas the quantizer Q_1 is used instead if $w_i = 1$. Thus, the Fibonacci lattice index n_i of X_i is modulated to $\tilde{n}_i$, where

$$\tilde{n}_i = \arg\min_n |\omega_F(n) - X_i|,\ \ \forall\ \omega_F(n) \in Q_j,\ \ j = \{0,1\}\ . \quad (9)$$

The watermarked image is then determined by converting the value in $L^*a^*b^*$ color space back to the RGB color space, where

(a) The Fruit image



(b) Fibonacci lattice

Figure 2: (a) The Fruit image. (b) The distribution of a^*b^* points for the "Fruit" image and the corresponding Fibonacci lattice points.

the a^* and b^* are the real and imaginary parts of $\tilde{X}_i$, respectively. Accordingly, by the modulations of the indexes of Fibonacci lattice points, a binary watermark bit-stream with length of total pixel number of the host image can thus be embedded into the chromatic component of a color host image, namely the embedding capacity is one bit per pixel.

As for the watermark extracting process, very few parameters are necessary for creating the Fibonacci lattice which is the same as the one used in the embedding process. If $\hat{X}_i$ is a chromatic point of the attacked watermarked image, the watermark message embedded in this pixel can be estimated by the index of the nearest lattice point of $\hat{X}_i$. That is,

$$\hat{m} = \begin{cases} 0, & \mathrm{mod}(\hat{n},2) = 0 \\ 1, & \mathrm{mod}(\hat{n},2) = 1 \end{cases} , \qquad (10)$$

where $\hat{n}$ is the index of the nearest lattice point of $\hat{X}_i$, which can be determined by

$$\hat{n}_i = \arg\min_n |\omega_F(n) - \hat{X}_i|, \;\; \forall\, \omega_F(n) \in Q_0 \cup Q_1 . \qquad (11)$$

Experimental Results

The experiments conducted in this study are to concurrently embed two watermark messages into the color host image. One fragile watermark is embedded into the chromatic component by the FLIM approach proposed in this paper, and the other robust watermark is embedded into the luminance component by the QIM approach [5]. Then, to let this hybrid watermarking be applicable, three requirements should be verified:

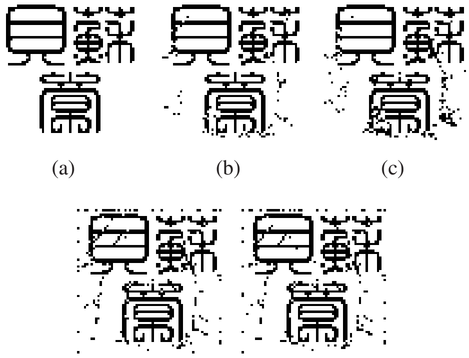
(a) PSNR = 40.54 dB, MOS=3.56

(b) PSNR = 37.38 dB, MOS=3.47

Figure 3: The watermarked images for: (a)embedding only in L^* (b)hybrid watermarking.

1. The watermarked image of hybrid watermarking should possess the comparable visual quality, compared with the watermarked image where only the robust watermark was embedded in the L^* component.
2. The performance of the robust watermark should not be considerably degraded even though the watermarked image of hybrid watermarking conveys additional authentication information.
3. The authentication function of the fragile watermark should be proved, which is usually examined by the capability to locate a slight modification on the watermarked image.

The most widely used objective quality assessment in watermarking context is the peak signal-to-noise ratio (PSNR), in sense of MSE (mean squared error), of which noise power is measured based on the Minkowski summation of squared intensity differences of the host and watermarked image pixels. Compatible with many proposed results, this study found the PSNR value does not truly present the visual perception of the watermarked image. Accordingly, the subsequent simulation results present visual quality of the watermarked image not only by the PSNR value, but also by the subjective evaluation of the *mean opinion score* (MOS). To determine MOS of each image, the viewer gives each image a rating as follows: (1) bad; (2) poor; (3) fair; (4) good; (5) excellent. Then, the MOS is given by averaging the scores, and may range from 1(worst) to 5(best).



(a) (b) (c) (d) (e)

Figure 4: The extracted watermark images: (a) The original watermark, (b) and (c) are the extracted watermark images when the Gaussian noise attacks Figs. 3(a) and 3(b), respectively, (d) and (e) are the extracted watermark images when Figs. 3(a) and 3(b) are respectively compressed by JPEG standard.

Figure 3(a) shows the watermarked image for only embedding a robust watermark message as shown in Fig. 4(a)[1] in the L^* component of the host image which is shown in Fig. 2(a). In addition to the robust watermark, Fig. 3(b), the watermarked image of hybrid watermarking, conveys a fragile watermark[2] in its chromatic component. From the MOS values of these two images, it can be observed that, even though the numerical PSNR values of Fig. 3(b) appears worse than that of Fig. 3(a), but actually, the visual quality of these two images are almost the same. Thus, Figs. 3(a) and 3(b) illustrate that the proposed FLIM approach can unobtrusively embed a fragile watermark into the host image.

The robust performance of a watermarking approach is usually measured by the error probability of the extracted watermark from the attacked watermarked image. If the embedded watermark message is a bi-level image as shown in Fig. 4(a), Figs. 4(b)-4(e) show the extracted watermark images from Figs. 3(a) and 3(b) for Gaussian noise attack and JPEG compression. Obviously, the proposed FLIM approach does not seriously degrade the performance of the robust watermark embedded in the luminance component.

As for the authentication function of the fragile watermark, this work embeds a random binary bit-stream into the entire host image with the capacity of one bit/pixel by the proposed FLIM approach. Various types of unaware modifications thus alter the watermarked image pixels of which corresponding pixels in Fig. 5(a) are black. To examine the capability of locating the modifications, the extracted watermark message is compared to the original one, and shows the pixels of different values in black, as shown in Figs. 5(b), 5(c), and 5(d). Obviously, the results show the proposed FLIM approach not only retains the function of robust watermark embedded in L^* component, but also performs a good capability of authenticating the integrity of the watermarked image. Moreover, if the modification is partly applied, the infected zone can also be located.

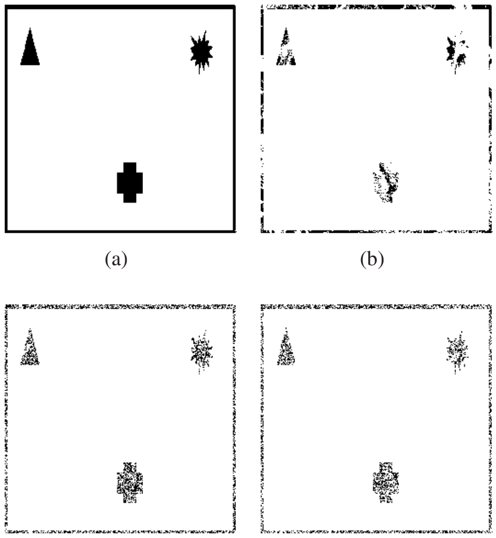
Conclusions

Inheriting the good visual quality of Fibonacci lattice applied to color quantization, a novel image watermarking approach, FLIM, based on the modifications of the indexes of Fibonacci lattice points, is specifically proposed for color image watermarking. The simulation results have shown that the proposed FLIM approach unobtrusively embeds a fragile watermark into the host image.

Combined the FLIM approach with the QIM approach which embeds another robust watermark into the luminance component, the hybrid watermarking system embeds two watermark messages concurrently. This paper experimentally shows the proposed FLIM approach not only retains the function of robust watermark embedded in the luminance component, but also performs a good capability to locate the slight modifications on the watermarked image. With two watermark messages embedded for different purposes, the hybrid watermarking system can be applied to a variety of scenarios.

[1] Without loss of generality, the bi-level image can be regarded as a sequence of binary bit-stream.

[2] The fragile watermark used herein is a random binary bit-stream.



(a) (b) (c) (d)

Figure 5: (a) For those places in black, the corresponding in Fig. 3(b) will be modified. The detected patterns for: (b) increase in blue component by 20%, (c) Gaussian noise superimposition, (d) averaging over a 3×3 block.

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