Copyright Protection by Watermarking for Color Images against Rotation and Scaling Attacks Using Coding and Synchronization of Peak Locations in DFT Domain

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ABSTRACT

The proposed method for copyright protection of color images against rotation and scaling attacks is described. The main idea is to embed a watermark as coefficient-value peaks circularly and symmetrically in the middle band of the DFT domain of an input image. Then, by detecting the peaks in the DFT domain, the embedded watermark can be extracted.

Keywords

watermarking, color image, rotation attack, scaling attack, DFT domain, peak location coding, synchronization peak, copyright protection.

1. INTRODUCTION

Digital watermarking is a technique for embedding a watermark into an image to protect the owner's copyright of the image. The embedded watermark must be robust. The stego-image may be rotated or scaled by illicit users. It is desirable that after applying these operations on the stego-image, the watermark is not fully destroyed and can be extracted to verify the copyright of the image.

Many different watermarking techniques for copyright protection have been proposed in recent years. Watermarking techniques that are robust to rotation and scaling are mostly performed in the frequency domain. O'Ruanaidh and Pun [1] proposed the use of Fourier-Mellin transform-based invariants for digital image watermarking. A public watermarking method based on the Fourier-Mellin transform and an extension of it based on the Radon transform was proposed by Wu, et al. [2]. In Lin, et al. [3] a watermark is embedded into a one-dimensional (1-D) signal obtained by taking the Fourier transform of the image, re-sampling the Fourier magnitudes into log-polar coordinates, and then summing a function of those magnitudes along the log-radius axis. Su and Kuo [4] proposed a spatial-frequency composite digital image watermarking scheme to make the embedded watermark survive rotation and scaling transformations. The frequency-domain watermark was embedded in the discrete Fourier transform coefficients. The spatial-domain watermarking is used to help recover the image to its original orientation and scale.

This paper is organized as follows. In Section 2, the idea of the proposed method will be described. By certain properties of the DFT coefficients, we can embed a watermark in the DFT domain with robustness against rotation and scaling attacks. In Section 3, the proposed watermark embedding process is presented. In Section 4, the proposed watermark extraction process is described. In Section 5, some experimental results are illustrated. Finally, in Section 6 some discussions and a summary are given.

2. Idea of Proposed Method

2.1 Properties of Coefficients in DFT Domain

After applying a discrete Fourier transformation (DFT) to an input image, the DFT coefficients in the frequency domain can be obtained. The DFT of an image $f(x,y)$ of size $M \times N$ can be described by the equation described below:

$$F(u,v) = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(ux/M+vy/N)} \quad (2.1)$$

The Fourier transform is a complex function of the real frequency variables. It has several properties, and some of them are described in the following.

A. Symmetry property

If a 2D signal is real, then the Fourier transform has a symmetry property, as shown by the following equation [5]:

$$F(u,v) = F^*(-u,-v)\,. \quad (2.2)$$

The symbol (*) indicates complex conjugation. Because the Fourier transform of an image can be complex, we can divide it into two functions. One is the *magnitude* function or spectrum $|F(u,v)| = [R^2(u,v) + I^2(u,v)]^{\frac{1}{2}}$, and the other the *phase* function $\phi(u,v) = \tan^{-1}\left[\frac{I(u,v)}{R(u,v)}\right]$, where $R(u,v)$ and $I(u,v)$ are the real and imaginary parts of $F(u,v)$. And for real signals, Equation (2.2) leads to:

$$|F(u,v)| = |F(-u,-v)|. \quad (2.3)$$

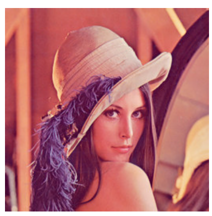
It means that the magnitude value of a coefficient (or simply a coefficient value) and its symmetric version are equal. In addition, both the magnitude and the phase functions are necessary for complete reconstruction of an image from its Fourier transform. But the magnitude part is less important than the phase part. The magnitude-only image is unrecognizable. On the contrary, the phase-only image is barely recognizable [6]. Therefore, we may calculate and adjust the magnitude values of the DFT coefficients to embed information without causing significant loss of image quality.

B. Invariant properties of rotation and scaling

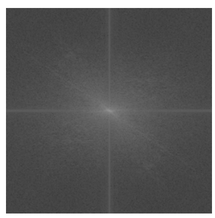
After we apply some image processing operations like rotation and scaling to an image, the coordinates and magnitude values of the DFT coefficients of the image will be altered, too. Changes of the DFT coefficients after scaling and rotation operations in the discrete image domain are listed in Table 1 [7]. The scaling operation has almost no effect on the DFT coefficients. It means that when an image is scaled, each DFT coefficient is the same as the original one except only with some noise. On the other hand, after rotating an image in the spatial domain, the locations of the DFT coefficient values will have the same rotation in the DFT domain. Figures 1(a) and (b) show an original image and a rotated version of it. And the corresponding Fourier spectrum images, in which each pixel value is equal to the magnitude value of the DFT coefficient, are shown in Figures 1(c) and (d), respectively. Note that the Fourier spectrum image in Figure 1(d) has the same rotation like Figure 1(b).

Table 1. Changes of DFT coefficients after operations in discrete spatial domain.

Operations	Scaling	Rotation
Changes of DFT coefficients	Almost no effect	Rotation

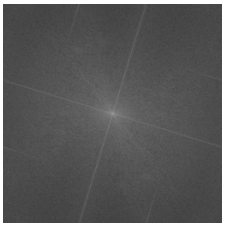


(a)



(c)

(b)



(d)

Figure 1 Input images, and Fourier spectrum images of G channel. (a) Image “Lena”. (b) Image “Lena” after rotation. (c) Fourier spectrum image of image “Lena” (d) Fourier spectrum image with the same rotation angle of (b).

2.2 Properties of Color Channels

A full-color image has three color channels, namely, red (R), green (G), and blue (B). Generally speaking, we can embed watermark information into all of these three channels. However, human eyes are less sensitive to the frequency of blue color. And its greatest sensitivity is distributed over the region of the yellow/green frequency [8]. In addition, according to experiments, a watermark can be embedded into both red and blue channels in the DFT domain without creating perceivable effects. On the contrary, hiding information in the green channel is too sensitive to human vision. If we embed the watermark in the DFT domain of the green channel, the stego-image will appear to include obvious reticular effects.

2.3 Proposed Technique for Coding Peak Locations for Watermarking

In the proposed method, after the zero frequency point $F(0,0)$ is shifted to the center of the transform domain, a watermark is embedded in a ring region which covers a middle band in the frequency domain between two circles with radiuses R1 and R2, with R1< R2, as shown in Figure 2. The middle band of the DFT domain is divided into n equally-spaced concentric circles, each with a radius $r \in R = \{r_1, r_2, \cdots, r_n\}$ and into m angle ranges with each range starting at a direction $\theta \in \Theta = \{\theta_1, \theta_2, \cdots, \theta_m\}$, as seen in Figure 3. Then, an embeddable position $p_k \in P = \{p_1, p_2, \cdots, p_l\}$, where the coefficient value is adjusted to be a peak, is selected to be located at (x_k, y_k) described by:

$$(x_k, y_k) = (r_i\cos\theta_j, r_i\sin\theta_j) \tag{2.4}$$

where $0<i<n$, $0<j<m$ and $0<k<l = n\times m$.

In addition, we already know that the DFT of a real image has the complex conjugate property (2.2), and that the coefficient values have the symmetric property (2.3). Furthermore, when conducting a watermarking work by changing the coefficient values, we must preserve the positive symmetry [9] in the following way:

$$|F(u, v)| \rightarrow |F(u, v)| + \delta$$
$$|F(-u, -v)| \rightarrow |F(-u, -v)| + \delta \tag{2.5}$$

where δ is a pre-selected constant. This means that if the value of an embeddable position is changed, the coefficient value of the symmetric location must also be adjusted with the same amount in the mean time.

In the proposed method, let $M(u, v)$ be a coefficient value, which equals $|F(u, v)|$ and $M'(u, v)$ be the modified value. A watermark W is taken to be a serial number in this study and it is converted into a bit stream $W = w_1w_2\cdots w_K$, which we call a *watermark bit stream*, with bit length K. Then, when conducting the watermarking work, the value of $M'(u, v)$ is modified to be a peak by the following equation:

$$M'(u,v) = M(u,v) + c \times w_i \tag{2.6}$$

where c is a pre-selected factor that determines the embedded watermark strength and w_i is the *i-th* bit value (1 or 0) of W, called a *watermark bit*.

During watermarking, because of the property of the DFT coefficients specified in (2.5), we must select a pair of coefficients at (x_k, y_k) and $(-x_k, -y_k)$ and adjust them to be peaks simultaneously. Otherwise, a peak will be counteracted by the symmetric coefficient value after applying the inverse DFT. In addition, if a watermark bit w_k equals “1,” the coefficient values of the corresponding embeddable location (x_k, y_k) and its symmetric location ($-x_k$, $-y_k$) are adjusted in this study to be peaks to embed the watermark bit by Eq. (2.6). On the contrary, if w_k equals "0," the values of the coefficient pair are not changed.

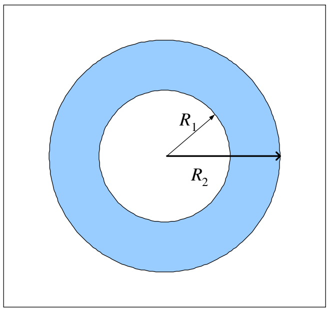


Figure 2 A ring region of middle frequency band.

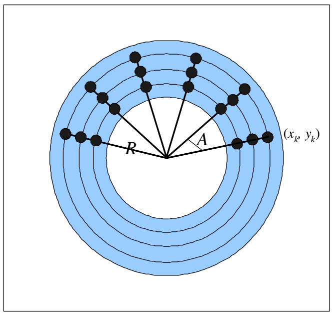


Figure 3 The ring region divided into concentric circles and into angular sectors.

2.4 Proposed Technique for Synchronizing Peak Locations for Protection against Rotation and Scaling Attacks

In order to deal with rotation and scaling attacks, an extra peak P_{syn} is used in this study to synchronize the peak locations and is embedded into the middle frequency band of the DFT domain at the location described as follows:

$$P_{syn}(x, y) = (r\cos\theta_{ori}, r\sin\theta_{ori}) \quad (2.7)$$

where r is selected to be larger than R_2 and θ_{ori} is a pre-selected constant. We adjust the magnitude M of P_{syn} to be $M' = M + c$, where c is a constant mentioned previously.

In the watermark extraction process, we use P_{syn} to calculate the rotated angle of a tampered image which suffered from a rotation attack. Because of the DFT property shown in Table 2.1, if a stego-image is rotated, the location of P_{syn} is changed with the same angle of rotation. We calculate the new angle θ'_{ori} of P_{syn}. The difference $\Delta\theta$ between θ'_{ori} and θ_{ori} can be use to decide whether the stego-image has suffered from a rotation attack. Then, The angles θ'_k of the remaining peaks are obtained. Finally, we use $\Delta\theta$ and θ'_k to reconstruct the original angles θ''_k of the remaining peaks by the following equations:

$$\theta''_k = \theta'_k - \Delta\theta . \quad (2.8)$$

In addition, according to the DFT property shown in Table 1, if an image is scaled, the coefficient values of the DFT domain are almost unaffected. It means that the radiuses of the peaks will not be changed.

3. Watermark Embedding Process

As mentioned previously, a watermark used for image ownership protection is assumed to be a serial number in this study, and the watermark is transformed into a watermark bit stream. In this section, the process of embedding a watermark bit stream in a color image will be described.

3.1 Embedding of Watermarks

In the proposed watermark embedding process, we use the two channels of red and blue to embed a watermark bit stream in the DFT domain according to the idea described in Section 2.2. And the middle band area of the Fourier spectrum is divided into several concentric circles. Then, the watermark bit stream is embedded in the region of the concentric circles.

Furthermore, the watermark bit stream is divided into two halves to be embedded in the red and blue color channels, respectively. For either channel, the spatial domain is transformed into the frequency domain by the DFT. In the middle band of the DFT domain, locations that can be use to create peaks are decided according to the scheme described in Section 2.3. Then, we can get pairs of locations (x_k, y_k) and ($-x_k$, $-y_k$). Using the watermark bit stream W, if a bit wk of W equals

"1," coefficient values of the corresponding embeddable positions (x_k, y_k) and ($-x_k$, $-y_k$) are adjusted to be peaks by Eq. (2.6) to embed a watermark bit. On the contrary, if wk equals "0", the corresponding coefficient values are not changed. In addition, a synchronization peak is also embedded into the middle frequencies according to the scheme described in Section 2.4.

3.2 Detailed Algorithm

The inputs to the proposed watermark embedding process are a color image C and a watermark W. The output is a stego-image S. The process can be briefly expressed as an algorithm as follows.

Algorithm 1: *Watermark embedding process.*
Input: A given color image *C* and a watermark *W*.
Output: A stego-image *S*.
Steps.

1. Transform the red and blue channels of *C* into the frequency domain by the DFT to get C'_{red} and C'_{blue}.
2. Transform *W* into binary form $W = w_1w_2\cdots w_{2l}$ with length $2l$, and divide *W* equally into two parts $W_{\text{red}} = w_1w_2\cdots w_l$ and $W_{\text{blue}} = w_{l+1}\cdots w_{2l}$.
3. Embed W_{red} and W_{blue} into C'_{red} and C'_{blue}, respectively, by performing the following operations.
   3.1 Decide *n* radiuses R = $\{r_1, r_2,\cdots, r_n\}$ of equally-spaced concentric circles in the middle band between two circles with radiuses R_1 and R_2, with $R_1 < R_2$.
   3.2 Decide *m* angles $\Theta = \{\theta_1, \theta_2,\cdots, \theta_m\}$ equally distributed in the range from 0° to 180°. Also, take *l* to be $m \times n$.
   3.3 Obtain *l* positions P = $\{p_1, p_2,\cdots, p_l\}$ with p_k (k = 1, 2, …, l) located at ($r_i\cos\theta_j$, $r_i\sin\theta_j$) with $k = (i - 1)\times m + j$, and their *l* symmetric positions Q = $\{q_1, q_2,\cdots, q_l\}$ with q_k located at the symmetric location of p_k, where $1 \le i \le n$, and $1 \le j \le m$.
   3.4 If the value of the watermark bit w_k equals 1, then adjust the pair of the coefficient values located at p_k and q_k to be peaks by Eq. (2.6), where $1 \le k \le l$.
   3.5 Add a synchronization peak P_{syn} according to the scheme described in Section 2.4.
4. Transform the C'_{red} and C'_{blue} back into the spacial domain by the inverse DFT.
5. Take the final result as the desired stego-image *S*.

4. Watermark Embedding Process

In the proposed watermark extraction process, no other information but the stego-image is needed as the input. The watermark can be extracted to verify the copyright. The processes of applying this technique will be described in this section. And a detailed algorithm for the process will be given.

4.1 Extraction of Watermarks

In the proposed watermark extraction process, the red and blue channels of a stego-image are accessed. Each of these two channels is transformed into the DFT domain. Then, the peaks in the middle frequency band of the DFT domain are detected using a pre-selected threshold value *T*. If any DFT coefficient value *M* is larger than *T*, it is judged to be a peak. Because of the symmetric property of the DFT coefficient values specified in Eq. (2.3), we can only detect peaks within the range of the upper-half Fourier spectrum image. After collecting all the peaks, a detected peak with the longest radius is taken to be the synchronization peak, which is then used to synchronize the peak locations, and its angle θ'_{ori} is obtained. Then, we reconstruct the angles of the remaining *h* peaks in P = $\{p_1, p_2,\cdots, p_h\}$ by Eq. (2.8) to get their new locations P' = $\{p'_1, p'_2,\cdots, p'_h\}$.

Also, we separate the ring area of the middle frequency band between two circles with radiuses

R'_1 and R'_2, with $R'_1 < R'_2$, into n equally-spaced homocentric circles and into m sectors to make the middle frequency band become l areas D = {d_1, d_2,⋯, d_l}, where $l = m \times n$, as seen in Figure 2.5. Then, the P' and D are compared to decide the bits of a watermark bit stream $W = w_1 w_2 \cdots w_l$ by the following way:

$$w_k = \begin{cases} 1 & \text{if certain } p_i' \in d_k, \\ 0 & \text{otherwise}, \end{cases} \quad (4.1)$$

where $0 < k \le l$ and $0 < i \le h$. This means that, if there is a peak within an area d_k, the bit w_k is set to be "1"; otherwise, "0". Finally, transform the bit stream into an integer number as the extracted watermark. This completes the extraction process of the watermark.

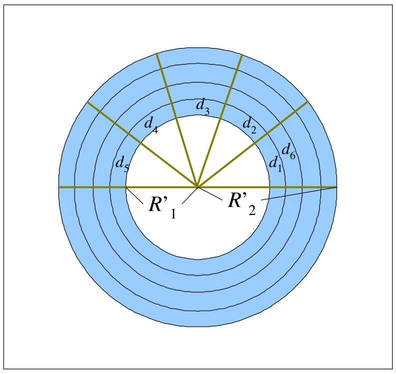


Figure 4 The middle frequency band is separated into concentric circles and into angular sectors.

4.2 Detailed Algorithm

The input to the proposed watermark extraction process includes just a stego-image S. The output is a watermark W that is a serial number embedded presumably in S. The extraction algorithm can be expressed as an algorithm as follows.

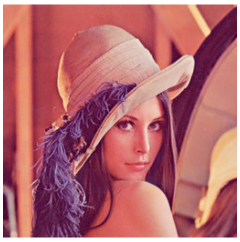
Algorithm 2: *Watermark extraction process.*
Input: A stego-image *S*.
Output: A watermark *W*.
Steps.

1. Transform the red and blue color channels of *S* into the DFT domain to get Fourier spectra S'_{red} and S'_{blue}.
2. Detect peaks within the upper-half areas of S'_{red} and S'_{blue}, respectively, by performing the following operations.
   2.1 Use a threshold value T to detect peaks in the middle-frequency band. If a coefficient value is larger than T, it is considered as a peak.
   2.2 Select a peak with the longest radius to be the synchronization peak, and calculate its changed angle $\Delta\theta$ with respective to the original angle of the synchronization peak.
   2.3 Reconstruct the angles of the remaining h peaks by Eq. (2.8) to get their new locations P′ = {p'_1, p'_2,⋯, p'_h}.
   2.4 Divide the middle frequency band between R'_1 and R'_2 into n equally-spaced concentric circles and into m sectors to make the middle band become several areas D = {d_1, d_2, ⋯, d_l}, where $l = m \times n$.
   2.5 Compare P′ and D to decide the watermark bit stream according to the way specified by Eq. (4.1).
3. Link two watermark bit streams from S'_{red} and S'_{blue} sequentially.
4. Transform the linked watermark bit stream into a serial number.
5. Take the final result as the desired watermark *W*.

5. Experimental Results

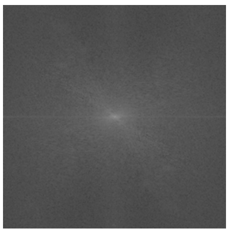
Some experimental results of applying the proposed method are shown here. A serial number 877 is transformed into binary form to be a watermark bit stream. The factor c that determines the embedded watermark strength is assigned to be 1.5. Figure 5 shows an input image with size 512×512. And Figure 6(a) shows the stego-image of Figure 5 after embedding the watermark. In addition, Figures 6(b) and (c) show the corresponding Fourier spectrum image and the detected locations of the peaks marked with red and green marks. The green mark is the synchronization peak. Figure 6(d) show a rotated image of Figure 6(a) and the corresponding Fourier spectrum image and the detected peak locations are shown in Figures 6(e) and (f), respectively. It shows that the Fourier spectrum image have the same angle of rotation with the tampered image. Figure 7(a) shows a scaled image of Figure 6(a) and the corresponding Fourier spectrum image with the detected peak locations are shown in Figure 7(b). The embedded peaks can be successfully detected in our experiments.

Figure 5 An input image “Lena”.

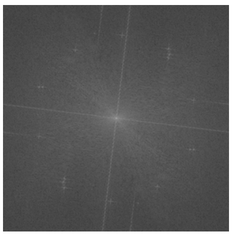


(a)

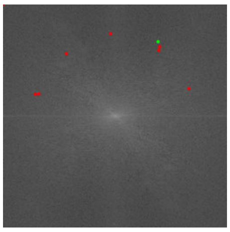
(d)



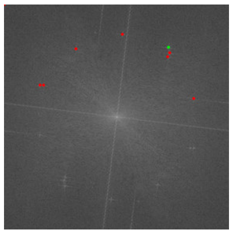
(b)



(e)



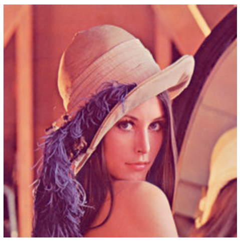
(c)



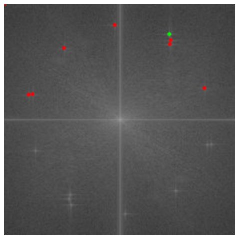
(f)

Figure 6 An output stego-images with the watermark, the tampered image and Fourier spectrum images. (a) Stego-Image “Lena”. (b) Fourier spectrum image of (a). (c) Peak locations of (c). (d) Tampered image after rotating 13 degree clockwise. (e) Fourier spectrum image of (d). (f) Peak locations of (e).

Figures 8(a) and (b) show two other color images both with size 512×512. And the corresponding stego-images after embedding the watermark are shown in Figures 8(c) and (d), respectively. The corresponding PSNR values are shown in Table 2, which show that the quality of each of the stego-images is still good. And the embedded watermark is imperceptible by human vision.



(a)



(b)

Figure 7 The tampered image and the Fourier spectrum image. (a) Tampered image after scaling to 90%. (b) Fourier spectrum image of (a) with peak locations.

(a)

(c)

(b)

(d)

Figure 8 Input images, and output stego-images with the watermark. (a) Image "Pepper". (b) Image "Jet". (c) and (d) Stego-images after embedding the watermark, respectively.

Table 2. The PSNR values of recovered images after embedding watermarks.

	Lena	Pepper	Jet
PSNR	33.0	33.0	33.0

6. Discussions and Summary

In this chapter, we have proposed a method for embedding a watermark into a color image by coding and synchronization of coefficient-value peak locations in the DFT domain. According to the properties of image coefficients in the DFT domain, we embed the watermark by creating the peaks circularly and symmetrically in the middle frequencies. On the other hand, an extra synchronization peak is added to synchronize the peak locations. The embedded watermark is shown to be robust and can survive the rotation and scaling attacks by the experimental results. The proposed method can achieve the goal to protect image copyright of the owner.

However, in the proposed watermark embedding method, the capacity of hiding data is not large. It is not enough to embed a logo image. In future works, it may be tried to solve this problem.

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