Copyright Protection against Print-and-Scan Operations by Watermarking for Color Images Using Coding and Synchronization of Peak Locations in Frequency Domain*

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A watermarking method for copyright protection of color images against print-and-scan operations is proposed. A watermark is embedded in an input image as coefficient-value peaks that are circularly and symmetrically distributed in a middle band of the discrete Fourier transform (DFT) domain of the input image. By detecting the robust peaks in the DFT domain of a reproduced image obtained by scanning a printed version of a watermarked image, we can extract the embedded watermark to verify the copyright of the reproduced image. Experimental results are given to prove the feasibility of the proposed method.

Keywords: digital watermarking, color image, copyright protection, print-and-scan operations, discrete Fourier transform, reproduced image

1. INTRODUCTION

Because of the rapid development of electronic products, printers and scanners are commonly used to publish and reproduce documents. Digital images can be printed and distributed. And when a printed image is scanned, the resulting image, called the reproduced image in this paper, becomes a digital version similar to the original one, though with some distortion occasionally. Such reproduced images can be misused such that the copyright of the original digital image is violated. It is therefore desired to have a means to counteract such illegal print-and-scan operations, sometimes called *print-and-scan attacks*.

Digital watermarking is a technique that embeds a watermark into a digital image to protect the owner's copyright of the image. The resulting watermarked digital image is called a *stego-image*. One way to solve the above-mentioned print-and-scan problem is to make the embedded watermark robust against print-and-scan operations, so that after these operations are applied to a stego-image to yield a reproduced image, the watermark

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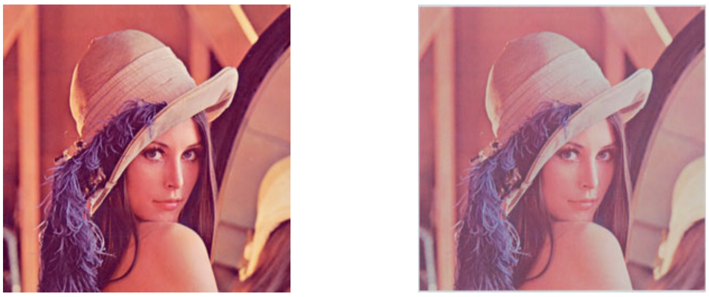
is not fully destroyed and can still be extracted from the reproduced image to verify the copyright of the image.

Some researches on watermarking techniques for copyright protection against print and scan attacks have been reported in recent years. Fleet and Heeger [1] described a human color vision model designed to ensure that the embedded signal is invisible and a method for embedding sinusoidal signals, which act as a grid and provide a coordinate frame for the image. Solachidis and Pitas [2] proposed using a private key, which allows a very large number of possible watermarks, to determine a watermark that is then embedded in a ring in the DFT domain. A correlation measure is used for watermark detection. Lefebvre *et al*. [3] proposed a method that combines an additive watermarking algorithm in the spatial domain and a synchronization template in the Fourier domain. In Chotikakamthorne and Pholsomboon [4], a watermark constructed with a ring-shaped constraint is embedded in the spatial domain, and a sinusoidal function with random phases is used to generate each watermark ring.

In a reproduced image, there are two types of distortions, namely, geometric transformations and pixel-value changes. The former type includes rotation, scaling, padding, etc., and the latter includes changes of pixel values in luminance, contrast, gamma correction, chrominance, blurring, etc. [5]. Geometric transformations do not cause significant changes in the visual quality, but pixel-value changes do, as seen in Fig. 1.



(a) The original image "Lena."　　(b) Reproduced image of (a) at 100dpi.

Fig. 1. A color image and a reproduced image with degraded quality.

A watermark embedded in a reproduced image must have a certain degree of robustness against pixel-value changes and geometric transformations. In order to embed watermarks in a color image so that the image can survive geometric transformation attacks, certain invariant features of the image with respect to geometric operations should be adopted in designing the watermark. In addition, the embedded watermark must be imperceptible.

In this paper, we propose a robust method for embedding a watermark in an input image as a set of coefficient-value peaks that are circularly and symmetrically distributed in a middle band of the discrete Fourier transform (DFT) domain of the input image. The peaks are robust in the DFT of the reproduced image and can be extracted to verify the copyright of the image. Experimental results are given to prove the feasibility of the proposed method.

The remainder of this paper is organized as follows. In section 2, the idea of the proposed method is described. 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 given. Finally, some conclusions are drawn in section 6.

2. IDEA OF PROPOSED METHOD

2.1 Properties of DFT and Color Images

The DFT $F(u, v)$ of an input image $f(x, y)$ of size $M \times N$ can be described by

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

This transform has several properties that are useful for this study. First, it has a symmetry property [6], shown by

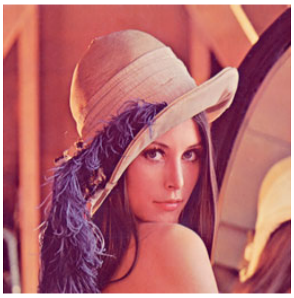
$$F(u, v) = F^*(-u, -v), \tag{2}$$

where the symbol F^* means the complex conjugate of F. Also, the complex transform $F(u, v)$ can be divided into two parts, the *magnitude function* (or called *spectrum*) $|F(u, v)| = [R^2(u, v) + I^2(u, v)]^{1/2}$ and the *phase function* $\phi(u, v) = \tan^{-1}[I(u, v)/R(u, v)]$, where $R(u, v)$ and $I(u, v)$ are the real and imaginary parts of $F(u, v)$, respectively. For real inputs like images, Eq. (2) leads to

$$|F(u, v)| = |F(-u, -v)|, \tag{3}$$

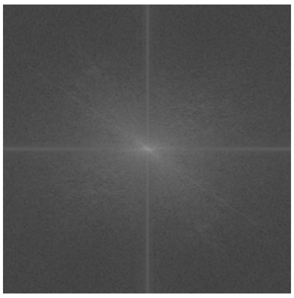
which means that a coefficient value and its symmetric version in the DFT domain are equal in magnitude. Both the magnitude and the phase functions are required for reconstruction of an input image from its DFT. The magnitude function is less important than the phase function. The magnitude-only image is unrecognizable, while the phase-only image is barely recognizable [7]. Therefore, we can compute and adjust the magnitudes of the DFT coefficients to embed information without causing significant loss of image quality, as was done in this study.

Furthermore, it is known [5] that the rescaling operation has almost no effect on the DFT coefficients, while image rotation in the spatial domain will cause the coefficient values to have the same rotation in the frequency domain. Figs. 2 (a) and (b) show an image and a rotated version of it. And the corresponding spectrum images, in which each pixel value is taken to be the magnitude of a DFT coefficient, are shown in Figs. 2 (c) and (d), respectively. Notice that the rotation of the spectrum image in Fig. 2 (d) is the same as that of the image in Fig. 2 (b). Finally, it is noted that although we can embed watermark information into all three color channels of an image, experiments have

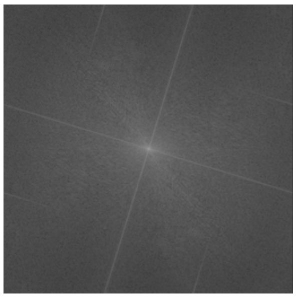


(a) The image "Lena."

(b) "Lena" after rotation.



(c) Fourier spectrum of "Lena."



(d) Fourier spectrum with the same rotation as in (b).

Fig. 2. Input images and Fourier spectrums of the G channel.

shown that this work can only be conducted in the red and blue channels in the DFT domain because information hidden in the green channel is easily detected by the human eye [8] and will have perceivable effects.

2.2 Proposed Watermarking Technique Using Coefficient-value Peaks in DFT Domain

In the proposed watermarking method, we first shift the zero frequency point $F(0, 0)$ to the center of the DFT domain and select a ring region in a middle band, denoted by B subsequently, in the DFT domain between two circles with two pre-selected radii R_1 and R_2, where $R_1 < R_2$, as shown in Fig. 3. Next, we divide B into n equally-spaced concentric circular stripes with outer radii $r_1, r_2, \ldots, r_n$, and divide each stripe into m angle ranges with starting angles $\theta_1, \theta_2, \ldots, \theta_m$, respectively, as shown in Fig. 4. Then, for watermark embedding, we select $n \times m$ locations $P = \{p_1, p_2, \ldots, p_{n\times m}\}$, called *embeddable positions*, in the frequency domain, with coordinates described by

$$p_k = (u_k, v_k) = (r_i\cos\theta_j, r_i\sin\theta_j), \tag{4}$$

where $1 \le i \le n$, $1 \le j \le m$, and $1 \le k \le \ell$ with $\ell = n \times m$. We also adjust the coefficient values of some of these positions so that they become *local peaks* in the frequency domain, thus forming a desired watermark in the manner described below.

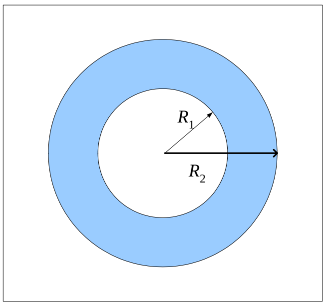


Fig. 3. A ring region in the middle frequency band.

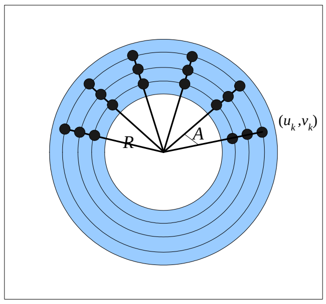


Fig. 4. The ring region in Fig. 3 is divided into concentric circular stripes, and each stripe is divided into angular sectors.

First, we select a number of peaks, say h ones, among the ℓ ones at the embeddable positions for use to embed a watermark W, which is a pre-selected series number with an integer value w. These peaks may be viewed to *code* the watermark value w.

To decide which peaks should be used, we apply a combinatorial operation to get all possible *codes* $R = \{r_1, r_2, \ldots, r_g\}$, with each code r_i specifying a set of h peak locations, where $g = C(\ell, h)$ with $C(\ell, h)$ being a *combinatorial number*, that is, the number of ways in which h *unordered* outcomes can be selected from ℓ possibilities. In this study, we set h to be equal to $\ell/2$ because $C(\ell, h)$ will then have the maximal value for a specific $\ell = m \times n$. For example, if ℓ is equal to four and h is equal to two, then we have $P = \{p_1, p_2, p_3, p_4\}$ and $g = C(4, 2) = 6$, which means that we have 6 possible codes $R = \{r_1, r_2, \ldots, r_6\}$ for use as watermarks, where $r_1 = \{p_1, p_2\}$, $r_2 = \{p_1, p_3\}$, $r_3 = \{p_1, p_4\}$, $r_4 = \{p_2, p_3\}$, $r_5 = \{p_2, p_4\}$, and $r_6 = \{p_3, p_4\}$.

Then, after choosing a watermark W with integer value w no larger than g, we get the wth code r_w in R and modify the coefficient values $M(u_k, v_k)$ of the corresponding embeddable positions p_k specified by r_w as local peaks $M'(u_k, v_k)$ according to the following equation:

$$M'(u_k, v_k) = M(u_k, v_k) + c, \tag{5}$$

where c is a pre-selected constant that determines the embedded watermark strength.

It should be noted that, when changing the coefficient value to become a peak at each $p_k = (u_k, v_k)$ for the amount of c, we must preserve the *positive symmetry* property of the DFT [9] by changing the corresponding coefficient value at $p_k' = (-u_k, -v_k)$ for the same amount c. Otherwise, the peak created at p_k will be counteracted by the unchanged symmetric coefficient value at p_k' after applying the inverse DFT. That is, we must perform, as is done in this study, the operation

$$M'(-u_k, -v_k) = M(-u_k, -v_k) + c \tag{6}$$

each time we calculate Eq. (5).

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

In order to deal with rotation and scaling attacks, an extra local peak P_s, called the *synchronization peak*, is created in the DFT domain to serve as a signal for *synchronizing* the peak locations $P = \{p_1, p_2, \ldots, p_{n\times m}\}$ mentioned previously in a way described later. P_s is embedded into the middle frequency band B as well at a location p_s described by

$$p_s = (u_s, v_s) = (r_s\cos\theta_s, r_s\sin\theta_s), \tag{7}$$

where r_s is selected to be larger than R_2 (the outer radius of the band B) and θ_s is a pre-selected angle value. We also apply Eqs. (5) and (6) to adjust the DCT value of P_s and that of its symmetric version so that they become peak values.

We now describe how we use the synchronization peak P_s in the proposed watermark extraction process to calculate the rotation angle of a suspicious stego-image which possibly suffers from a rotation attack. Because of the DFT properties mentioned previously and illustrated in Fig. 2, if a stego-image is rotated, the location of P_s will also change with the same rotation angle. We can thus calculate the new angle θ_s' of P_s and take the difference $\Delta\theta$ between θ_s' and θ_s to decide whether the stego-image has been rotated in the following way: if $\Delta\theta \neq 0$, then it has been rotated; otherwise, not. If the stego-image is found to have been rotated, then we find the angles θ_k' of the other local peaks and recover their original angles θ_k'' as follows:

$$\theta_k'' = \theta_k' - \Delta\theta. \tag{8}$$

On the other hand, as mentioned previously, if a stego-image is rescaled, the DFT coefficient values are unaffected. This means that the radii of the local peaks will not be changed.

2.4 Proposed Technique for Automatically Adjusting Threshold Value for Extracting a Watermark

To extract an embedded watermark in a reproduced image, we have to detect, using a threshold value T, the local peaks in the DFT domain of the image to recover the code representing the watermark. Because the reproduced image has pixel-value changes which degrade the original image quality and counteract the values of the embedded peaks, the threshold value T is difficult to determine. The way adopted in this study to solve this problem is to select first an initial value T_0 for T and then adjust T to get a refined value in the ith iteration according to the following rule:

$$T_i = \begin{cases} T_{i-1} + \delta & \text{if } e_i > h, \\ T_{i-1} - \delta & \text{if } e_i < h, \end{cases} \tag{9}$$

where T_i is the value for T in the ith iteration, h is the previously-mentioned number of embedded peaks of each code, e_i is the number of the peaks detected using the threshold

$T_{i\text{-}1}$, and δ is a pre-selected constant. This means that if the number of detected peaks is larger than the number of embedded peaks, then the threshold value is incremented by the amount δ to reduce the number of detected peaks in the next iteration, and vice versa. The iterations stop at the moment when the number of detected peaks equals h. The detected peaks are then *decoded* to recover the embedded watermark value w.

3. WATERMARK EMBEDDING PROCESS

In the proposed watermark embedding process, first we rescale an input image to obtain a pre-selected $M \times M$ square image, where M is a radix-2 number. Next, we use radix-2 Fast Fourier Transform (FFT) to transform the input image into the DFT domain in a fast way. Then, we use the DFT domains of the red and blue channels of the input image to embed a series-number watermark. The watermark is transformed into a bit stream, which is then divided into two halves. Each half is transformed back to obtain an integer that serves as a smaller watermark to be embedded in one of the red and blue color channels according to the idea described in the previous section. The detailed algorithm for this process is given below.

Algorithm 1 *Watermark embedding process*

Input: a color image C and a watermark W.

Output: a stego-image S.

Step 1: Rescale C to get an $M \times M$ square image C', where M is a radix-2 number.

Step 2: Transform the red and blue channels of C' into the frequency domain by means of the DFT to get C_r' and C_b'.

Step 3: Transform W into a binary stream, divide the result equally into two substreams, and transform them back into two integers W_r and W_b.

Step 4: Embed W_r as a watermark W' into C_r' by performing the following operations.

- **4.1** Decide a set of radii $R = \{r_1, r_2, \ldots, r_n\}$ for n equally-spaced concentric circular stripes in the middle band B of the frequency domain between two pre-selected circles with radii R_1 and R_2, with $R_1 < R_2$.
- **4.2** Decide m angles $\Theta = \{\theta_1, \theta_2, \ldots, \theta_m\}$ equally distributed in the range from 0° to 180°, and take ℓ to be $m \times n$.
- **4.3** Obtain ℓ embeddable positions $P = \{p_1, p_2, \ldots, p_\ell\}$ with p_k ($k = 1, 2, \ldots, \ell$) being located at $(r_i\cos\theta_j, r_i\sin\theta_j)$ and i and j being such that $k = (i - 1) \times m + j$. Obtain also the ℓ positions $Q = \{q_1, q_2, \ldots, q_\ell\}$ symmetric to P with each q_k being located at the symmetric location of p_k.
- **4.4** Apply the combinatorial operation mentioned previously to get g codes $R = \{r_1, r_2, \ldots, r_g\}$, with each code r_k ($k = 1, 2, \ldots, g$) specifying a set of peak locations, where $g = C(\ell, h)$ with $h = \ell/2$.
- **4.5** According to the value w of W', take r_w out of R, and adjust the coefficient value at each location within r_w and that of its symmetric location as local peaks by Eqs. (5) and (6).
- **4.6** Add a synchronization peak P_s according to the scheme described in section 2.3.

Step 5: Embed W_b as a watermark W' into C_b' in a similar way to the above step.

Step 6: Transform C_r' and C_b' back into the spatial domain by the inverse DFT.
Step 7: Rescale C' to the original size of C.
Step 8: Take the final result as the desired stego-image S.

4. WATERMARK EXTRACTION PROCESS

In the proposed watermark extraction process, no information besides the stego-image under suspicion is needed as the input. The stego-image is rescaled to obtain a square image of the pre-selected size $M \times M$, where M is the radix-2 number mentioned previously. The red and blue channels are transformed into the DFT domain by using the FFT. Because of the symmetric property of the DFT coefficient values specified in section 2.1, we only need to detect local peaks within the range of the upper-half Fourier spectrum image. After all the peaks have been collected, a detected peak with the largest radius is taken as the synchronization peak P_s, which is then used to synchronize the other peak locations. Then, the angles of the remaining h peaks in $P = \{p_1, p_2, \ldots, p_h\}$ are reconstructed according to Eq. (8) to get their new locations $P' = \{p'_1, p'_2, \ldots, p'_h\}$.

Also, we separate the ring area of the middle frequency band B between the two circles with the previously-mentioned radii R_1 and R_2 into n equally-spaced concentric circles and into m angle ranges to make B a set of ℓ sectors $D = \{d_1, d_2, \ldots, d_\ell\}$, where $\ell = m \times n$, as shown in Fig. 5. Then, P' and D are compared to collect h sectors to form a set A as follows:

$$\begin{aligned}&\text{for all } k = 1, 2, \ldots, \ell \text{ and } i = 1, 2, \ldots, h,\\&\text{if } p_i' \text{ falls in } d_k, \text{ then regard } d_k \text{ as being in } A.\end{aligned} \tag{10}$$

This means that, if there is a peak within an area d_k, then d_k is taken to into A. Finally, we use a combinatorial operation with D and h as inputs to get g kinds of possible *codes* $R' = \{r_1', r_2', \ldots, r_g'\}$, where $g = C(\ell, h)$ with $h = \ell/2$. Then, we check if there is any r_j' which is equal to A with $1 \le j \le g$. If there is, the integer number j is then taken as the extracted watermark value. The detailed watermark extraction process is described by the following algorithm.

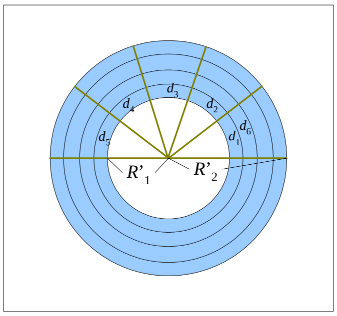


Fig. 5. The middle frequency band is divided into concentric sectors.

Algorithm 2 *Watermark extraction process*
Input: a stego-image S.
Output: a watermark W.
Step 1: Rescale S to get an $M \times M$ square image S' where M is a radix-2 number.
Step 2: Transform the red and blue color channels of S' into the DFT domain to get Fourier spectra S_r' and S_b'.
Stpe 3: Detect peaks within the upper-half areas of S_r' and S_b', respectively, by performing the following operations.
- **3.1** Use an adjusted threshold value T to detect peaks in the middle-frequency band according to the method described in section 2.4.
- **3.2** Select the peak with the largest radius as the synchronization peak and calculate its angle change $\Delta\theta$ with respect to the original angle of the synchronization peak.
- **3.3** Reconstruct the angles of the remaining h peaks using Eq. (8) to get their new locations $P' = \{p'_1, p'_2, \ldots, p'_h\}$.
- **3.4** Divide the middle frequency band between R_1 and R_2 into n equally-spaced concentric circles and into m angle ranges to change the middle band into several ℓ sectors $D = \{d_1, d_2, \ldots, d_\ell\}$, where $\ell = m \times n$.
- **3.5** Compare P' and D to select h areas as a set A according to the method specified by Eq. (10), where $h = \ell/2$.
- **3.6** Apply a combinatorial operation to get g codes $R' = \{r_1', r_2', \ldots, r_g'\}$, with each code r_j' ($j = 1, 2, \ldots, g$) specifying a set of h areas of D, where $g = C(\ell, h)$. Then, check if there is any r_j' equal to A with $1 \le j \le g$. If there is, take j as the desired serial number.

Step 4: Link two serial numbers in binary form from S_r' and S_b' sequentially.
Step 5: Transform the linked bit stream into a serial number.
Step 6: Take the final result as the desired watermark W.

5. EXPERIMENTAL RESULTS

Some experimental results obtained by applying the proposed method will be discussed in this section. A serial number 888 was used as a watermark. The factor c that determines the embedded watermark strength was set to be 1.5. Fig. 6 shows an input

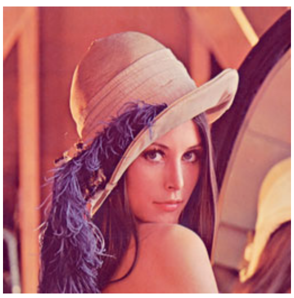
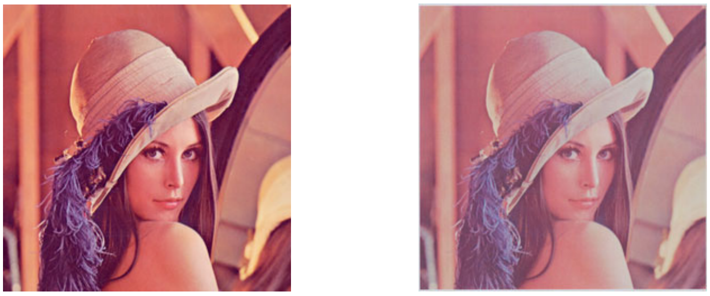
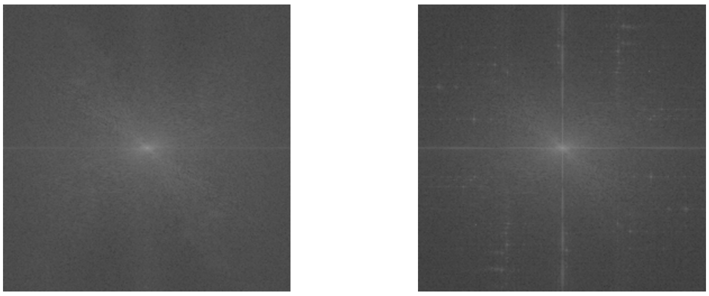


Fig. 6. The input image “Lena.”

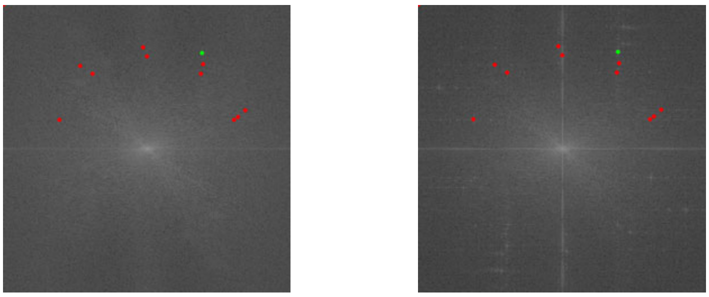
image of size 512 × 512. Fig. 7 (a) shows the stego-image of Fig. 5 after embedding the watermark. In addition, Figs. 7 (b) and (c) show the corresponding Fourier spectrum image and the detected locations of the peaks, indicated by red and green marks. The green mark is the synchronization peak. Fig. 7 (d) shows a reproduced version of Fig. 7 (a) obtained by printing (a) at 600dpi on an HP Color LaserJet 5500 laser printer and scanning the result at 100dpi using a Microtech Scanmaker 9800XL flatbed scanner. And the corresponding Fourier spectrum image and the detected peak locations are shown in Figs. 7 (e) and (f), respectively. The embedded peaks can be successfully detected in our experiments.



(a) Stego-image "Lena." (d) Reproduced image with a resolution of 100dpi.



(b) Fourier spectrum of (a). (e) Fourier spectrum of (d).



(c) Peak locations of (b). (f) Peak locations of (e).

Fig. 7. Output stego-images with the watermark, reproduced image, and Fourier spectra.

Figs. 8 (a) and (b) show two other color images, both of size 512 × 512. The corresponding stego-images after embedding the watermark are shown in Figs. 8 (c) and (d), respectively. The corresponding PSNR values are shown in Table 1, which shows that the quality of each of the stego-images is still good. The embedded watermark is imperceptible to the human eye.

(a) Image "Pepper."

(c) Stego-image after embedding the watermark in (a).

(b) Image "Jet."

(d) Stego-image after embedding the watermark in (b).

Fig. 8. Input images and stego-images with watermark.

Table 1. The PSNR values of recovered images after embedding watermarks.

	Lena	Pepper	Jet
PSNR	33.0	33.0	32.4

In addition, two reproduced images of Figs. 8 (a) and (b) are shown in Figs. 9 (a) and (b), with resolutions of 100dpi and 150dpi, respectively. The watermarks can be extracted successfully from each of these images by the proposed watermark extraction process in our experiments.

Finally, we tested 120 reproduced images, which were generated from twenty digital color images by printing at 600dpi and scanning at 85dpi, 100dpi, 150dpi, 200dpi, 250dpi, and 300dpi, respectively. The probability of successfully extracting the watermarks was 91.67%. The errors were mainly due to the use of improper image resolutions when rescanning the printed versions of the original input images.

(a) Reproduced image with a resolution of 100dpi.

(b) Reproduced image with a resolution of 150dpi.

Fig. 9. Some reproduced images of different quality levels.

6. CONCLUSIONS

In this paper, 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 the image coefficients in the DFT domain, we embed the watermark by creating peaks circularly and symmetrically in the middle frequencies. We also use a combinatorial operation to code the peak locations. In addition, an extra synchronization peak is added to synchronize the peak locations. In the watermark extraction process, the positions of the coefficient-value peaks are detected and mapped into a combinatorial operation to get a watermark. The embedded watermark is shown to be robust and able to survive print-and-scan operations. The proposed method can achieve the goal of protecting the image copyright of the owner.

However, by the proposed watermark embedding method, the capacity of a normal-size image is not large enough for hiding a common logo image. In future works, we may attempt to solve this problem.

REFERENCES

1. D. J. Fleet and D. J. Heeger, "Embedding invisible information in color images," in *Proceedings of the IEEE International Conference on Image Processing*, Vol. 1, 1997, pp. 532-535.
2. V. Solachidis and L. Pitas, "Circularly symmetric watermark embedding in 2-D DFT domain," *IEEE Transactions on Image Processing*, Vol. 10, 2001, pp. 1741-1753.
3. F. Lefebvre, A. Gueluy, D. Delannay, and B. Macq, "A print and scan optimized watermarking scheme," in *Proceedings of the IEEE Workshop on Multimedia Signal Processing*, 2001, pp. 511-516.
4. N. Chotikakamthorn and S. Pholsomboon, "Ring-shaped digital watermark for rotated and scaled images using random-phase sinusoidal function," in *Proceedings of the IEEE Region 10 International Conference on Electrical and Electronic Technology*, Vol. 1, 2001, pp. 321-325.
5. C. Y. Lin and S. F. Chang, "Distortion modeling and invariant extraction for digital

image print-and-scan process," in *Proceedings of the International Symposium on Multimedia Information Processing* (*ISMIP*), 1999.
6. R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, 2nd ed., Prentice Hall, New Jersey, 2002, pp. 155.
7. Properties of Fourier Transforms, http://www.ph.tn.tudelft.nl/Courses/FIP/noframes/fip-Properti-2.html.
8. A. Navarro and J. Tavares, "Joint source-channel PCM image coding for binary symmetric channels," in *Proceedings of the International Conference on Signal Processing Applications and Technology*, 1999.
9. J. O'Ruanaidh, W. J. Dowling, and F. M. Boland, "Phase watermarking of digital images," in *Proceedings of the IEEE International Conference on Image Processing* (*ICIP '96*), Vol. 3, 1996, pp. 239-242.

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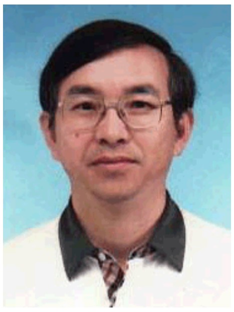

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