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Performance analysis on a watermarking method based on double random phase encoding technique

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ABSTRACT

When digital watermarking is used for piracy tracking, different watermarks are needed to be embedded into different distributions of a digital product. Based on double random phase encoding (DRPE) technique, cascaded-phases iterative algorithm and random-phase-shift algorithm, Chen et al. proposed a method to generate many different embedded watermarks from one reference watermark, while the embedded watermark can be recognized by testing the correlation between the recovered watermark and the original reference watermark. In this way, only the reference watermark instead of the embedded watermarks needs to be stored and managed. However, since the recovered watermark may be different from the embedded watermark, especially under any image processing, the correlation between the recovered watermark and the reference watermark may be different from the correlation between the embedded watermark and the reference watermark, which may result in wrong recognition. In this paper, the performance of Chen's method was analyzed with numerical simulations. The results indicated that, to correctly recognize the embedded watermark, the number of generated embedded watermarks with Chen's method is limited.

1. Introduction

The double random phase encoding (DRPE) technique was a typical optical image encryption technique [1], which has been widely studied [2–4] and has also been used to image hiding and watermarking [5,6].

Digital watermarking is mainly used to protect the copyright of digital products by embedding the copyright information, i.e., the digital watermark, into the digital products. The copyright can be proved by extracting or detecting the embedded copyright information from the digital product [7,8].

If the same digital watermark is embedded into many copies of a digital product for distribution, the watermark can only prove the copyright owner, while cannot tell the originality of piracy. To track the sources of illegal copies, different watermarks should be embedded into different distribution versions, which results in the requirement of generating, storing and managing many different watermarks [4,7–9]. To solve this problem, Chen et al. proposed a method to generate many different embedded watermarks from one reference watermark based on double random phase encoding technique, cascaded-phases iterative algorithm (CPIA) and random-phase-shift algorithm [10]. To prove the copyright and track the source of piracy, the correlation between the recovered watermark and the reference watermark is calculated to recognize the embedded watermark. Thus, only the reference watermark instead of all of the embedded watermarks needs to be stored. However, since the recovered watermark may be different from the embedded watermark due to computational errors, especially under any image processing, the correlation between the recovered watermark and the reference watermark may be different from the correlation between the embedded watermark and the reference watermark. This will influence the accuracy of watermark detection and piracy source tracking. In this paper, Chen's method is analyzed regarding the performance of watermark detection and piracy tracking.

The rest of this paper is organized as follows: in Section 2, Chen's method is briefly introduced and analyzed. Section 3 performs the numerical simulations to analyze the performance of Chen's method. In Section 4, the final conclusions are presented.

2. Introduction and analysis of Chen's method

2.1. Watermark generation and embedding

Firstly, an image is chosen as the reference watermark. Then, the reference watermark is encrypted into two random phase

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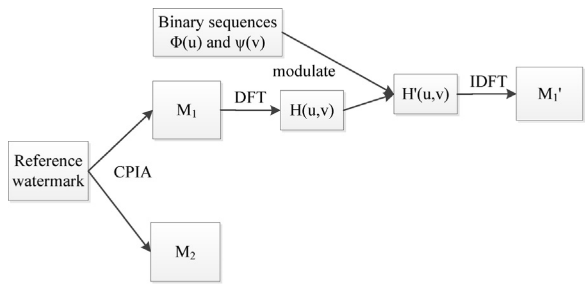

Fig. 1. Generate the embedded watermark.

masks (RPMs) with CPIA. Next, one RPM is modulated by two binary random sequences. Finally, the modulated RPM and another unmodulated RPM are used as the embedded watermark to be embedded into the host image.

2.1.1. Encrypt the reference watermark with CPIA

The cascaded-phases iterative algorithm (CPIA) is a DRPE-based iterative algorithm [11,12], which is used to encrypt the reference watermark.

Suppose the reference watermark $f(x,y)$ is a grayscale image with size of $M \times N$. By selecting two uniformly distributed random arrays, which are valued between $-\pi$ and π, an iteration involving $f(x,y)$ is applied. For each iteration, two random phase masks (RPMs) are obtained and the reference watermark can be reconstructed approximately with them. Since CPIA has a high convergence speed, with enough iteration, the reference watermark can be almost accurately reconstructed from the obtained random phase masks M_1 and M_2 as follows [10].

$$f'(x,y) = \text{abs}(F^{-1}\{F[M_1(x,y)]M_2(u,v)\}) \tag{1}$$

where $f'(x,y)$ is the reconstructed reference watermark. M_1 and M_2 can be viewed as the result of encrypting the reference watermark $f(x,y)$ with CPIA.

The detailed description of CPIA may be referred to Refs. [10–12].

2.1.2. Modulate one of the RPMs with random-phase-shift algorithm

After encrypting the reference watermark $f(x,y)$ with CPIA, two random phase masks M_1 and M_2 are obtained. Then, two uniformly distributed binary random series $\phi(u)$ and $\psi(v)$ are selected, where the values of the elements in $\phi(u)$ are $+\theta_1$ or $-\theta_1$, while the values of the elements in $\psi(v)$ are $+\theta_2$ or $-\theta_2$. By using $\phi(u)$ and $\psi(v)$, one of the RPMs, say M_1, is modulated to M_1' with random-phase-shift algorithms. The detailed description of modulating one of the RPMs with random-phase-shift algorithm may be referred to Ref. [10].

The phase masks M_1' and M_2 are used as the embedded watermark, which will be embedded into the host image following the method in Ref. [13].

Note that when various values of θ_1 and θ_2 are selected, different embedded watermarks will be obtained by modulating the phase masks M_1 with random-phase-shift algorithm. In this way, different embedded watermarks can be generated from one reference watermark.

The procedure of generating the embedded watermark is shown in Fig. 1.

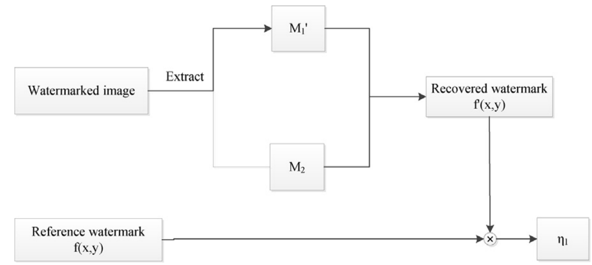

Fig. 2. Detect the embedded watermark.

2.2. Watermark detection and piracy tracking

2.2.1. Watermark detection

For watermark detection, M_1' and M_2 are extracted from the watermarked image. Then, the recovered watermark $f'(x,y)$ is obtained as.

$$f'(x,y) = \text{abs}(F^{-1}\{F[M_1'(x,y)]M_2(u,v)\}) \tag{2}$$

The correlation between the recovered watermark $f'(x,y)$ and the reference watermark $f(x,y)$ can be obtained as.

$$\eta_1 = \frac{cov[f(x,y), f'(x,y)]}{\sigma_f \sigma_f'} \tag{3}$$

where cov$[f(x,y), f'(x,y)]$ is the cross-covariance between $f(x,y)$ and $f'(x,y)$, σ_f and σ_f' are the standard deviation of $f(x,y)$ and $f'(x,y)$, respectively.

The watermark detection procedure is shown in Fig. 2 [10].

The correlation coefficient η_1 can be used to recognize the embedded watermark to track the source of the tested product as the following subsection described.

2.2.2. Piracy tracking

As Section 2.1 described, by selecting various values of θ_1 and θ_2, different embedded watermarks are obtained. The values of the correlation coefficient η_1 between the recovered watermark and the reference watermark will also be different. Therefore, the value of the correlation coefficient η_1 can be used to recognize the embedded watermark for piracy tracking.

As Ref. [10] described, suppose two copies of a multimedia product will be distributed to user A and user B. With CPIA and random-phase-shift algorithm, two different embedded watermarks can be generated from one reference watermark and the values of the correlation coefficient η_1 are different. For example, for user A, one copy is distributed by embedding one generated embedded watermark and the value of η_1 is 0.8, while for user B, another copy is distributed by embedding another generated embedded watermark and the value of η_1 is 0.5. Then, the source of a copy can be recognized from the value of the correlation coefficient between the recovered watermark and the reference watermark.

2.3. Analysis of watermark recognition

However, the above procedure of watermark detection and piracy tracking is based on the ideal situation, namely, the value of the correlation coefficient η_1 between the recovered watermark and the reference watermark can accurately reflect the correlation degree of the embedded watermark and the reference watermark. Due to computational errors, the extracted M_1' and M_2 may be a little different from the embedded ones, which may result in slightly change of the value of η_1 compared to the original one. Therefore, to distinguish the embedded watermark via the correlation between the recovered watermark and the reference watermark, the value