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Fast Watermark Synchronization Based on Complementary Templates

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Abstract

A recent trend of the digital watermark requires not only the robustness but also speed. To achieve these requirements, we propose a watermark synchronization scheme based on two kinds of templates. The first one is the rotation invariant template for estimating scale parameter, and the second is the scale invariant template for estimating rotation parameter. Theoretically, complementary templates greatly reduce the search space at the detection stage and achieve robustness against the RST distortion. The results report that the proposed method is useful for the watermark detection system which requires both a real-time detection and robustness.

Keywords

Digital Image Watermarking; Template Matching; Affine Transform; Real-Time Detection

1. Introduction

In the age of the Internet, digital contents have become one of the most popular information sources. Because the Internet is an excellent distribution system for digital contents, copyright protection of digital contents is required. Digital watermarking is one of the most popular technologies for the copyright protection of digital contents such as images, videos, and audio.

The digital watermark is a code that can be embedded in various forms of digital content, but is generally invisible to people. However it is detectable by electronic devices such as computers, networks, and mobile devices. Digital watermarks applied to digital contents are persistent, staying with the content through copying, manipulation, and so on. Traditionally, the watermark is used for copyright protection of published contents. But a recent trend of the digital watermark not only protects the published contents but also used for enhancing the user's experience [1].

The aspects of user experience, the watermarks can be applied in many directions, especially the mobile device environment. For example, Digimarc discovery [2] uses the image watermark in printed advertisements to

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provide a uniform resource locator (URL) of additional resources.

In order to enable these kinds of services, the watermark is easily detected and extracted by a mobile device. However, the detection of the watermark through the mobile devices is much harder due to their relatively low hardware performance. Moreover, the capturing environments are diverse because of the unsteady holding of the device, and a variety of camera resolutions. Therefore, the detection process must require less computation power and be robust against various kinds of distortions, especially the rotation, scale, and translation (RST).

To cope with these kinds of difficulties, we propose an efficient watermarking synchronization method based on the two kinds of templates. The first one is the rotation invariant template for estimating scale parameter, and the other is the scale invariant template for estimating rotation parameter. Theoretically, complementary templates greatly reduce the search space at the detection stage and achieve robustness against the RST distortion.

The rest of this paper is organized as follows. Section 2 explains problems of previous works in watermark detection by mobile device. In Section 3, we define the complementary templates and describe a theoretical analysis of them. And we present our test environments and results in Section 4.

2. Problems of Previous Works

To cope with difficulties in watermark detection with RST distortions, various schemes have been proposed. These methods use the discrete Fourier transform (DFT) to achieve robustness against rotation and scaling. The DFT based methods can be divided into two categories, one is based on the invariance [3-5], and another is based on template matching [6,7].

The invariance based watermarking using the log-polar-mapping (LPM) scheme is theoretically perfect for the RST distortions. However, most of these algorithms are difficult to implement, because the LPM and the inverse LPM distort the embedded watermark. The template matching based algorithms are relatively easy to implement and have good performance for various geometric distortions. However, in order to estimate the distorted parameter using a template, most of those algorithms consume much computation resource. Because of their complexity of computation, those algorithms are not suitable for mobile applications.

3. Proposed Method

We propose an efficient watermarking synchronization method based on the two kinds of templates. The templates contain no information but are only an indicator to recover possible transformation in the image. **Table 1** show the estimation parameter and invariance property of each template.

The template T_ρ is rotation invariant template for estimating scale parameter, and T_θ is scale invariant template for estimating rotation parameter. Because each template has invariance for estimating a parameter of the other one, they complement each other. In this paper, we refer to these templates as complementary templates.

3.1. Templates Definition

As shown in **Figure 1**, proposed templates are embedded in a transformed domain of host image $f(x1, x2)$ defined in following Equation (1):

$$F(k1, k2) = \mathscr{F}[f(x1, x2)], \tag{1a}$$

$$F_L(k\rho, k\theta) = \mathscr{L}[F(k1, k2)], \tag{1b}$$

$$I\rho(\xi\rho, k\theta) = \mathscr{F}[F_L(k\rho)], \tag{1c}$$

$$I\theta(k\rho, \xi\theta) = \mathscr{F}[F_L(k\theta)]. \tag{1d}$$

Table 1. Functions of the templates.

ID	Estimation parameter	Invariance
T_ρ	scale (ρ)	rotation
T_θ	rotation (θ)	scale

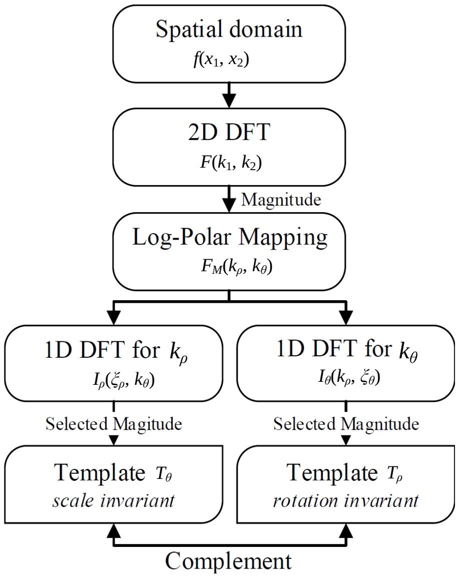

Figure 1. Diagram for the proposed templates.

where $\mathscr{F}[\cdot]$ and $\mathscr{L}[\cdot]$ are computation operator for the discrete Fourier transform (DFT) and Log-polar mapping (LPM) respectively. The complementary templates are defined as magnitude points in $I_\rho(\xi_\rho, k_\theta)$ and $I_\theta(k_\rho, \xi_\theta)$ domains as following Equation (2):

$$T_\theta:\ (t_\rho,\ c_\theta)\ \in\ I_\rho(\xi_\rho,\ k_\theta) \tag{2a}$$

$$T_\rho:\ (c_\rho,\ t_\theta)\ \in\ I_\theta(k_\rho,\ \xi_\theta) \tag{2b}$$

where t_ρ, t_θ are the values for the position of templates and c_ρ, c_θ are constant values. The t_ρ and t_θ are used for the rotation and scale estimation parameters respectively. $I_\rho(t_\rho, c_\theta)$ and $I_\theta(c_\rho, t_\theta)$, the intensity of templates, shall be larger than a threshold value τ_ρ and τ_θ adaptively determined in embedding process.

3.2. Properties of Templates

Using the definition in the previous section, we can briefly describe the properties of the proposed templates. As describe in Equation (1a), the proposed templates inherited the properties of DFT. The magnitude of the DFT is invariant to translation in spatial domain as shown in the Equation (3):

$$F(k1,\ k2)\ exp[-j(ak1+bk2)]\ \leftrightarrow\ f(x1+a,\ x2+b). \tag{3}$$

Spatial shifts affect only the phase representation of an image. ConsEquationuently, proposed templates obtain circular translation invariance in spatial domain.

The Equation (1b) shows the LPM of the DFT magnitudes. The LPM operation generates the 2-dimensional coordinate system F_L for scaling and rotation parameter [8]. If F_L is transformed by 1-dimensional DFT in the direction of k_θ, transformed domain I_θ for rotation parameter obtains shift invariance.

Therefore, the T_ρ is independent for an image rotation, and it is proper to estimate the scaling parameter. Similarly, the T_θ is independent for an image scaling, and it is suitable to estimate the rotation parameter.

3.3. Embedding Process

Templates are embedded in following steps:

1) Determine position of templates t_ρ and t_θ in transformed domain I_ρ and I_θ.
2) Determine the strength of the T_ρ, T_θ adaptively.
3) Calculate $F(k1, k2)$ domain magnitude from $I_\rho(t_\rho, c_\theta)$ and $I_\theta(c_\rho, t_\theta)$.
4) Add result of step 3) to the DFT magnitude of the original (or watermarked) image.
5) Apply inverse DFT to result of step 4) and get the template embedded image.

3.4. Detection Process

Templates are detected in following steps:

1) Apply 2-D DFT to the watermarked image.

2) Apply LPM to magnitude obtained in step 1).

3) Apply 1-D DFT to the direction of radius (k_ρ) and angle (k_θ) to get I_ρ, I_θ domain.

4) Find T_ρ in I_ρ domain for constant c_θ as following Equation (4) and determine the scaling parameter. If $I_\rho(\hat{\rho}, c_\theta) < \tau_\rho$ then the system decided that T_θ is not detected.

$$\hat{\rho} = \arg\max_{\xi_\rho}\left[I_\rho\left(\xi_\rho, c_\theta\right)\right] \tag{4}$$

5) Find T_θ in I_θ domain for constant c_θ as following Equation (5) and determine the rotation parameter. If $I_\theta(c_\rho, \hat{\theta}) < \tau_\theta$ then the system decided that T_ρ is not detected.

$$\hat{\theta} = \arg\max_{\xi_\theta}\left[I_\theta\left(\xi_\rho, c_\theta\right)\right] \tag{5}$$

6) (Optional) Recover the transformed image using estimated parameters $\hat{\rho}$ and $\hat{\theta}$. The operator $\mathcal{S}(\rho)[\cdot]$ and $\Re(\theta)[\cdot]$ denote the rotation and scaling transformation for their input parameter.

$$F`(k1,\ k2) = \mathcal{S}^{-1}(\rho)\cdot\Re^{-1}(\theta)\cdot F(k1,\ k2) \tag{6}$$

7) Extract watermark using the result of detection process.

We note that the flat-top window [9] is applied in before the DFT calculation to reduce the leakage.

3.5. Time Complexity of the Detection Process

Due to the improvement of hardware, FFT on the mobile device is no longer treated as a time consuming

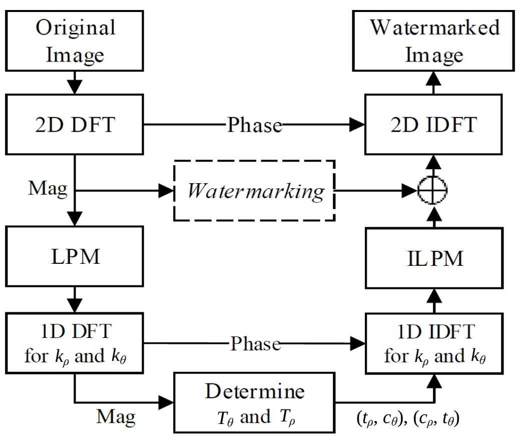

Figure 2. Embedding process.

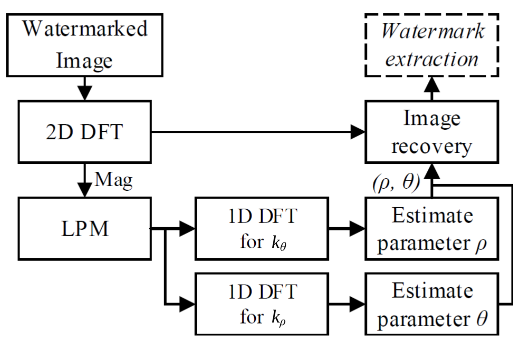

Figure 3. Detection process.

computation [10]. And depending on its implement, LPM can be computed in a constant time. Therefore, to show the usefulness of a proposed method, we analyze the complexity of the template searching step.

As shown in **Figure 4(a)**, computation complexity of previous approach for rotation and scaling template searching is $O(\rho \cdot \theta) = O(n2)$, since the template is dependent to both rotation and scaling parameters. On the other hand, as shown in **Figure 4(b)**, a computation complexity of a proposed method is $O(\rho) + O(\theta) = O(n)$. Because each complementary template has invariance for estimating a parameter of the other. For example, the system searches only I_ρ domain for a constant c_θ to detect T_ρ, because of a rotation invariance of I_ρ and T_ρ. In this way, complementary templates greatly reduce the search space at template detection stage.

3.6. Watermark System for a Proposed Method

As mentioned in the beginning part of this section, there is no information in the complementary templates. The templates only provide an invariant domain for a watermarking algorithm. In order to build an actual watermarking system, a proper watermarking algorithm should be prepared.

The required watermarking algorithm has to have a shift invariance property for spatial domain, since the templates cannot recover the translation of the original image. The watermarking algorithm also requires fast and simple computation to utilize the contribution of complementary templates the fast estimation. Therefore, simple DFT based watermarking algorithms [11,12] are suitable for the proposed domain.

In addition, if a mobile device provides a streaming capturing process such as viewfinder mode, we can improve a performance of proposed domain. The signal of watermarks in proposed domain is cumulative, since the proposed domain is invariant for RST distortion.

4. Results

4.1. Experimental Setup

In order to obtain a robust system, several parameters of our algorithm have to be carefully set. We have found experimentally that normalized frequencies for c_ρ and c_θ are 0.44 and 0.60, respectively. In order to make templates invisible, all parameters are set to yield a PSNR no greater than 35 dB. The thresholds τ_ρ and τ_θ are set so that false positive rates are minimized. We use the image of Lena to test proposed method. In order to test the robustness of the proposed schemes, the tests consisted of the combination of attacks: rotation, and scaling.

With the above setup, a machine consisting of Intel i7-3770 (3.40 GHz) with 16 GB main memory is used to measure the detection performance. Matlab R2012b environment is used to implement and execute our algorithm.

4.2. Template Detection Result

Figure 5 shows the sample template embedded images and the transformed domain of **(a)** and **(b)**. To make the **Figure 5(d)**, template embedded image is resized by 1.2 and rotated by 30˚.

The complementary templates are shown as small white dots in the transformed domain highlighted 10 times brighter. The properties of template are observed in **Figure 5**. For example, vertical positions of the peaks in **Figure 5(e)** are not changed after the scaling. Similarly, horizontal positions of the peaks in **Figure 5(f)** are not changed after the rotation.

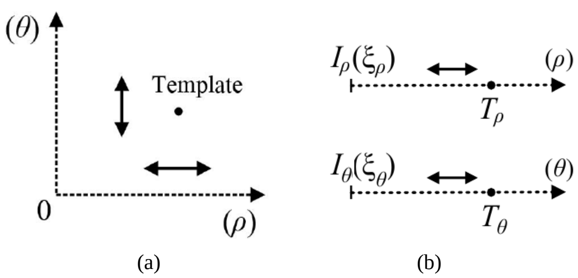

Figure 4. Geometric interpretation of search space for scaling and rotation parameter. (a) Previous methods; (b) Proposed methods.

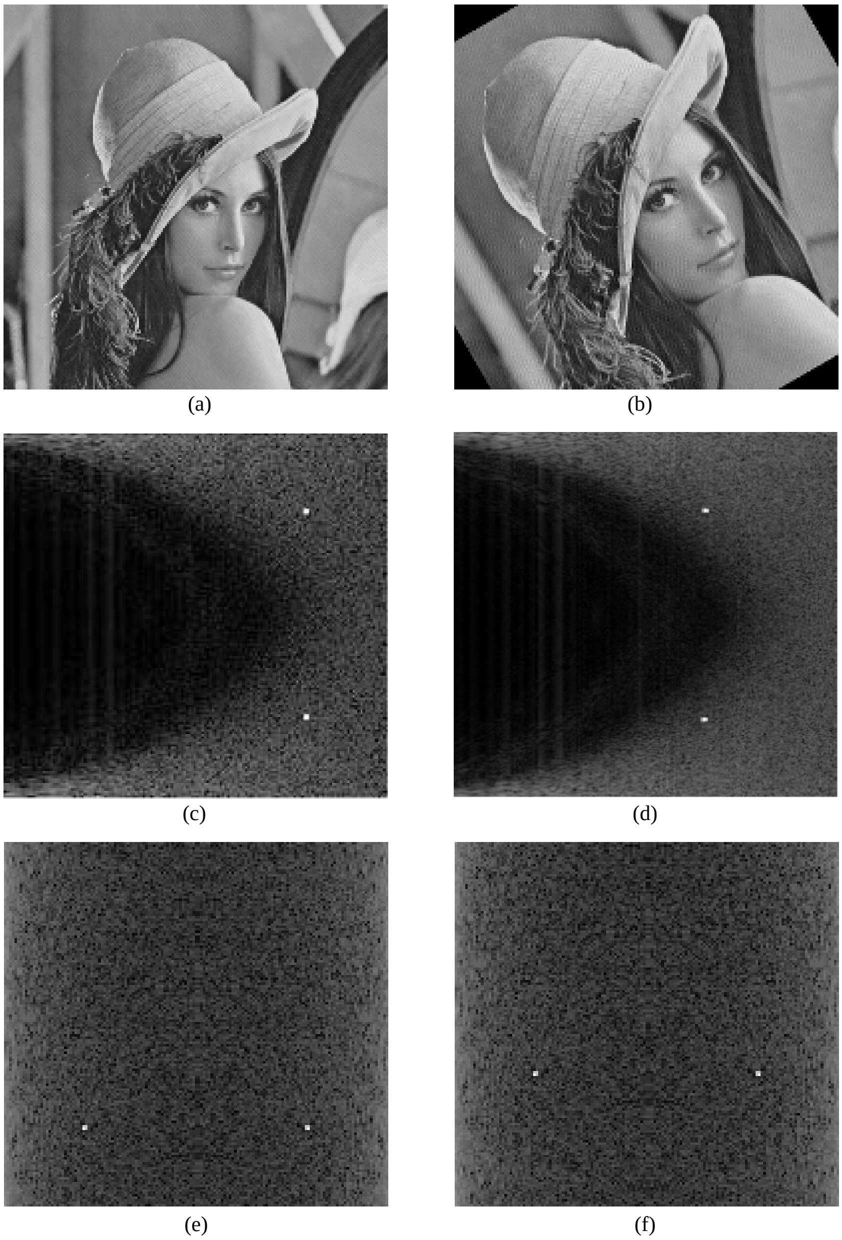

Figure 5. (a) is a template embedded image, (d) is a distorted version of (a), and transformed domain of (a) and (d). Templates are shown as small white dots. (c) I_ρ domain of (a); (d) I_ρ domain of (b); (e) I_θ domain of (a); (f) I_θ domain of (b).

Figure 6 reports the detection accuracy of the complementary templates for the rotation and scaling. The results report that the proposed method provides the robustness to the scaling, rotation, and combination of both transforms.

4.3. Time Consumption Result

In the template detection stage, the proposed method takes a total of 107 milliseconds to estimate rotation and scaling parameters. 85 milliseconds are consumed for computing I_ρ and I_θ domains, and only 1 millisecond is spent on finding the templates. We should note that most of the computation occurred in the Log-polar mapping which consists of several resampling processes. If the Log-polar mapping process is optimized for time consumption, we can greatly reduce the whole computation time.

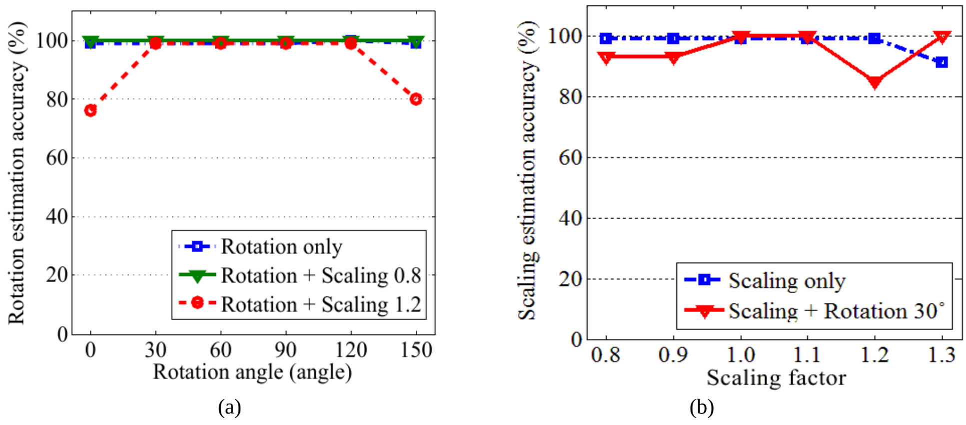

Figure 6. Robustness to (a) Rotation; (b) Scaling.

5. Conclusions

The main contribution of the complementary templates is a real-time estimation of scaling and rotation parameters. Therefore, the watermark detection algorithms with our methods no more require robustness for the rotation and scaling distortion. It allows the design of a watermark detection algorithm that concentrates on only a detection speed. Especially, it is useful as a watermark detection system for mobile devices that require both real-time detection and robustness.

However, our proposed method is not perfectly protected against other geometric distortions such as shearing and projection. Therefore, our future work will concentrate on coping with other geometric distortions. We also plan to design a proper watermarking algorithm for our proposed domain.

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