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Geometrically resilient digital watermarking scheme based on radial harmonic Fourier moments magnitude

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ABSTRACT

It is still a challenging work to design a robust image watermarking scheme to resist geometrical transformations. In this paper, we analyze the geometric invariant properties of radial harmonic Fourier moments (RHFMs), and propose a new geometrically resilient digital image watermarking scheme based on RHFMs magnitudes. Firstly, the binary watermark image is encrypted by Arnold transform, and the RHFMs of the host image are computed. Then, the accurate and robust RHFMs are selected according to the moment magnitude distribution. Finally, the encrypted watermark is embedded by quantizing the magnitudes of the selected RHFMs, and the watermarked image is obtained by adding the compensation image to the original host image. Experimental results show that the proposed RHFMs based image watermarking scheme outperforms other moments based watermarking methods, and is robust to a wide range of attacks, e.g., median filtering, random noise addition, JPEG compression, rotation, and scaling, etc.
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1. Introduction

Distribution channels such as digital music downloads, image/video-on-demand, and multimedia social networks pose new challenges to the design of content protection measures aimed at preventing copyright violations. Digital watermarking has been considered a potential solution to providing further protection of digital content. The close integration of the hidden signal, i.e., digital watermark, with the host media (such as video, image, audio, and text) can be used for declaring/verifying the ownership of the content, controlling the software/hardware operations or for the trailer tracking purposes [1]. In most of the related applications, the digital watermark signal has to be robust against the "watermark attacks," including lossy compression, signal processing procedures and even malicious watermark-removal operations, etc. For still images, the requirement of digital watermark surviving geometrical transformations is necessary since such manipulations as rotation, scaling and translation are common. Nevertheless, these procedures cause challenging synchronization problems for watermark detection. Special care has to be taken so that the embedded watermark can survive such attacks to achieve the related functionalities in the target application [2,3].

In the last decade, researchers have made the great efforts in developing image watermarking to resist geometrical transformations, and several geometrically invariant image watermarking approaches have been developed. These schemes can be roughly divided into *Exhaustive search, Spread spectrum modulation*, *Template insertion*, *Feature-based embedding*, and *Invariant domain* [4,5].

1.1. Exhaustive search

Since the hidden signal usually exists in the geometrically distorted watermarked image, exhaustive geometrical search is a feasible solution if a known hidden signal is the searched target [3]. Lichtenauer et al. [6] examined the false positive watermark detection of this methodology to show its feasibility. One challenge is to determine all the possible geometrical distortions in advance. The computational cost in the large search space and the dramatic increase of the false alarm probability during the search process are concerns of the exhaustive search.

1.2. Spread spectrum modulation

It is probably the most popular approach for data hiding, which spreads the digital watermark over the host image. Spread spectrum embedding could be implemented by two main ways, namely

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additive and multiplicative spread spectrum embedding [7]. The additive spread spectrum scheme uniformly spreads the watermark bit over the host image while the multiplicative spread spectrum spreads the watermark bit according to the host contents. Since the original host image is generally not available at the watermark decoder side, blind decoders are usually employed. Its robustness against common image processing operations and some geometric distortion, and its simple decoder structure make spread spectrum attractive for image watermarking. Despite these advantages of spread spectrum modulation, the interference effect of the host image, which causes the watermark decoding performance degradation, is a major concern of the spread spectrum modulation [8,9].

1.3. Template insertion

Employing synchronization templates may be a more flexible approach. The template is usually the repeated structure or tiling of signals that will help to reflect the distortion or manipulation applied on the image. The watermark detector can reverse the geometrical operation according to the extracted template for the watermark detection [10,11]. The detection of template is based on local autocorrelation. However, the embedded template signal is unfortunately, for both watermarker and attacker, easily detectable and removed, which causes inevitably problems for the watermark detection [12].

1.4. Feature-based embedding

It is a new watermark resynchronization techniques, which uses image content to recover the watermark after geometrical transformations. For feature-based embedding schemes, the basic strategy is to bind a watermark with the geometrically invariant image features, so the detection of the watermark can be conducted with the help of features [13]. However, some drawbacks indwelled in current feature-based schemes restrict the performance of watermarking system. First, the image feature extraction is usually sensitive to image modification. Second, watermark capacity is often limited, because the watermark is embedded into the feature based on local regions [3,14–16].

1.5. Invariant domain

The obvious way to achieve resilience against geometric distortions is to use an invariant domain. In [17–21], the watermark was embedded in an affine-invariant domain by using Fourier–Mellin transform, generalized Radon transform, singular value, polar harmonic transform, and histogram shape respectively. Despite that they are robust against geometrical transformations, these techniques usually suffer from implementation issues.

Invariant image moments is another kind of invariant domain for embedding the robust watermark. Image moments are efficient image content descriptors, which have the advantage to fully reconstruct the initial image after the embedment of the watermark information. Moreover, the invariant properties of the moments to remain unchanged under common geometric transformations significantly increase the robustness of the watermarks in such kind of attacks. Yap et al. [22] constructed a new method that gives the opportunity to control the insertion of the watermark not only by adjusting the embedding strength but also by defining its embedment location by controlling the Krawtchouk moment parameters. Xin et al. [23] proposed an image watermarking method by using Zernike moments (ZMs) and pseudo-Zernike moments (PZMs). In order to reduce the effects of computational errors and make ZMs suitable for image watermarking, Fahmy et al. [24] proposed to use Bspline interpolation to interpolate between image pixels. Due to the smooth and robust performance of Bspline interpolation, significant image quality improvements can be achieved. Zhu et al. [25] first presented an approach of RST invariant analysis for images. This approach achieves a set of completely invariant descriptors from the complex moments of the original image's Radon projection. Then, they proposed a watermarking scheme which can resist global geometric transforms. Elshoura and Megherbi [26] present an empirical comparative study of Tchebichef and ZMs in image watermarking applications. In particular, they consider the case of moment-based watermarking schemes involving moment watermarks being embedded in a given carrier image moments. Zhang et al. [27] proposed a new watermarking approach which allows watermark detection and extraction under affine transformation attacks. The novelty of the approach stands on a set of affine invariants derived from Legendre moments. Watermark embedding and detection are directly performed on this set of invariants. Singh and Ranade [28] proposed an invariant image watermarking based on a recently introduced set of polar harmonic transforms and angular radial transforms, and presented their comparative analysis with state-of-art approaches based on ZMs and PZMs. In paper [29], an image adaptive technique for high capacity watermarking scheme is introduced, in which accurate and fast radial harmonic Fourier moments is utilized. The high embedding capacity is achieved by improving the hiding ratio after reducing inaccuracies in the computation of moments. The binary watermark is embedded by performing the conditional quantization of selected moments magnitudes to minimize the spatial distortion added to the host image. Papakostas et al. [30] included a theoretical analysis and performance investigation of representative moment-based watermarking systems. Through a designed set of specific experiments, the influence of moment order and moment family (ZMs, PZMs, Wavelet, Krawtchouk, Tchebichef, Legendre, Fourier–Mellin) on each methods' performance is investigated and evaluated by applying geometric and signal processing attacks through the well-known benchmark Stirmark. Moreover, a comparative study regarding to methods' robustness, imperceptibility and algorithms' efficiency is achieved. Generally, moments based image watermarking approaches can resist geometrical transformations, but they are often faced with the problems of numerical instability of high order moments and computation errors, which inevitably degrade digital watermark recovery performance.

In 2003, Ren et al. [31] suggested to use triangular functions as radial kernels, and introduced new orthogonal moments named radial harmonic Fourier moments (RHFMs). Compared with other orthogonal moments, RHFMs has a better image reconstruction, lower noise sensitivity, and magnitude invariance to geometrical transformations. Besides, the RHFMs is free of numerical instability issues so that high order moments can be obtained accurately. So, RHFMs are more suitable for robust digital image watermarking. In this paper, we propose a new robust image watermarking based on RHFMs magnitudes, which can achieve both geometric invariance and high capacity data hiding. The novelty of the proposed algorithm includes: (1) The accurate and robust RHFMs selection strategy is discussed; (2) A new RHFMs magnitudes based robust image watermarking is proposed.

The rest of this paper is organized as follows. Section 2 recalls the preliminary about the radial harmonic Fourier moments (RHFMs). Section 3 analyzes the rotation, scaling, and translation (RST) invariant property of RHFMs magnitudes. Section 4 discusses the robust image watermarking using RHFMs magnitudes. Simulation results in Section 5 will show the performance of our scheme. Finally, Section 6 concludes this presentation.

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