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Color image watermarking based on quaternion Fourier transform and improved uniform log-polar mapping ☆

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ABSTRACT

In this paper, we propose a blind color image watermarking scheme based on quaternion discrete Fourier transform (QDFT) and on an improved uniform log-polar mapping (IULPM). The proposed watermarking scheme embeds dual watermarks: one is a meaningful binary image watermark and the other is a bipolar watermark. The former is embedded in the real part of mid-frequency QDFT coefficients using quantization index modulation. The latter is used to resynchronize the watermark after the watermarked image has been attacked, making the scheme resistant to geometric attacks. In particular, the IULPM allows for greater accuracy when estimating the rotation angle of a geometric attack. At the same time, the watermark embedding employs the image holistically, rather than in a block pattern. Experimental results demonstrate that the proposed scheme achieves better performance of robustness against both common signal operations and geometric attacks compared to other existing schemes.

1. Introduction

With the rapid development of Internet and sophisticated image editing tools, digital multimedia content can be replicated, as well as tampered with more easily, making copyright protection and content authentication a major concern. Digital watermarking is one of the mechanisms that can be used to address these issues. It provides access to data while, at the same time, maintains protection by means of an imperceptible watermark, i.e., a transparent protection. In past decades, digital watermarking has been widely studied using grayscale images, whereas color images have received much less attention though they constitute most of the displayed multimedia content. Color information is also viewed as a significant feature in many fields of image processing. If correctly handled, color information will lead to more effective watermarking schemes, especially when achieving a good trade-offs between imperceptibility and robustness.

When focusing on robust color image watermarking schemes, those working in transform-domains achieve satisfactory robustness in comparison with spatial-domain methods. These transforms mainly include discrete cosine transform (DCT)

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[1–3], discrete Fourier transform (DFT) [4], discrete wavelet transform (DWT) [5–9], and quaternion discrete Fourier transform (QDFT) [10–16].

Barni and Piva et al. [1] proposed to embed the watermark in a subset of DCT coefficients for each color channel while exploiting the characteristics of the human visual system (HVS) and the correlation between RGB channels in order to achieve a good trade-off between robustness and imperceptibility. These schemes have better performance than those based solely on image luminance. Since then, several other DCT methods have been proposed [2,3]. In [2], Ahmidi et al. designed a color image watermarking method where just noticeable difference (JND) is used to select DCT coefficients in order to embed the watermark. Su et al. [3] proposed a blind color image watermarking based on DCT, and proved that embedding the watermark in the DCT direct current (DC) coefficient could be replaced by working directly into the spatial domain, which is simpler and has higher efficiency. Regarding DFT-based color image watermarking, Tsui et al. [4] designed a scheme that represents the host image in La^*b^* color space, and encodes the chromatic channels a^* and b^* into complex numbers $a + jb$. The watermark is then embedded in the frequency domain by using spatiochromatic DFT. DWT has also attracted interest. Al-Otum et al. [5] designed a blind watermarking method which performs DWT on the three color channels in order to construct a wavelet-tree, and then searches for robust bit host locations based on dominant relations. Chou et al. [6] proposed a perceptually tuned watermarking scheme by exploiting JND in the wavelet domain. Good watermark invisibility was obtained. Vahedi et al. [7] explored the effects of choosing different decomposition levels, filter-banks, color models, and channels. To realize blind watermark extraction, Su et al. [8] developed a dual color image watermarking based on integer wavelet transform and state coding.

In this work, we focus on QDFT-based color image watermarking. QDFT offers a sound way to jointly deal with the three channels of color images so that the watermark energy is spread into three channels simultaneously rather than into only one channel. QDFT was first applied to color image watermarking by Bas et al. [10]. This approach was performed by inserting a binary watermark bit into QDFT coefficients of 8×8 pixel blocks. Tsui et al. [11] proposed a scheme that performs QDFT in the La^*b^* color space. The advantage of this scheme is that the watermark is evenly spread into the luminance and chrominance components of the host image. Ma et al. [12] introduced a color image watermarking scheme that takes advantage of an invariant feature transform and utilizing a geometric correction strategy to enhance the robustness of the watermark against geometric attacks. A watermark bit is embedded in QDFT coefficients of blocks centered on each of the invariant feature points. A semi-blind scheme that combines quaternion singular value decomposition and QDFT was presented by Sun et al. [13]. Recently, Chen et al. [14] demonstrated how to fully utilize the 4-D quaternion frequency domain in order to embed a large capacity color image watermark in the case of the well-known quantization index modulation (QIM) [14–16]. Wang et al. [15] developed a QDFT-based blind color image watermarking algorithm where least squares support vector machine (LS-SVM) were combined with pseudo-Zernike moments to resist geometric attacks. In [16], a blind color image watermarking method was proposed to resist geometric attacks by combining the uniform log-polar mapping (ULPM) with QDFT.

Geometric attacks are considered to be the most challenging when designing a robust image watermarking scheme. It is noted that some schemes [17–20] are robust against geometric attacks by combining DFT and log-polar mapping (LPM). The LMP simplifies the effects of rotation and scaling transforms in the spatial system to shifts in the log-polar system [20]. It is important to note that these schemes [17–20] work on grayscale images. In [17], Ruanaidh et al. proposed a watermarking scheme that works with the Fourier–Mellin transform similar to the effect of combining LPM and DFT. The watermarked images obtained, however, were of poor quality due to the use of LPM and its inverse LPM (ILPM). Some solutions have been proposed to overcome this issue [18,19]. For example, Lin et al. [18] embedded a watermark signal in a 1-D signal obtained by the summing function of the LPM Fourier magnitude along the log-radius axis. Zheng et al. [19] performed ILPM to obtain the exact corresponding embedding positions in the Cartesian system and then embedded each watermark bit in the four neighboring points around these positions. Although this scheme [19] showed improvement, it suffered drawbacks from the interference distortions introduced by the ILPM. In the case of grayscale images, Kang et al. [20] proposed a blind watermarking scheme based on DFT and ULPM utilizing an extension of LPM, based on the increase of the sampling interval of the log-polar mapping from non-uniform to near uniform. This scheme not only greatly expands watermarking cardinality but also eliminates interpolation and interference distortions. Unfortunately, when the watermarked image is rotated, the fractional angles of rotation correction cannot be estimated correctly.

In this paper, we focus on color image watermarking robustness against geometric attacks, and propose a blind and robust scheme based on QDFT and an improved uniform log-polar mapping (IULPM). We extend the ULPM method [20] and propose the IULPM method to improve the correction precision of the ULPM. We also introduce a color image watermark resynchronization method, based on IULPM and QDFT, to resist geometric attacks.

The remainder of this paper is organized as follows. Section 2 introduces the proposed IILPM method and watermark resynchronization procedure. Section 3 describes the proposed scheme including watermark embedding and extraction procedures. Section 4 provides the results of the experiment and discussion. Finally, Section 5 concludes the paper.

2. Watermark resynchronization based on QDFT and IULPM

In this section, we introduce the watermark resynchronization method based on QDFT and IULPM. This method allows us to estimate the fractional angles of rotation that the watermarked image may have undergone and, consequently, increases