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Perceptual hashing for color images based on hybrid extraction of structural features

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ABSTRACT

In this paper, a novel perceptual hashing scheme for color images is proposed with the hybrid feature extraction mechanism. During the stage of pre-processing, image normalization, Gaussian low-pass filtering and singular value decomposition (SVD) are applied on original image to improve the robustness of the scheme. In order to fully extract the structural features, the circle-based and the block-based strategies are exploited to sample the salient edge points with the aid of Canny operator, and then the color vector angles, which can effectively describe color pixel information, are calculated for the sampled points. Finally, after quantizing and scrambling the variances of the color vector angles for these sampled points, the image hash can be generated securely. Experimental results demonstrate that our scheme can achieve satisfactory performances with respect to perceptual robustness and discrimination.

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1. Introduction

Accompanying with the rapid development of the technique for digital signal processing, digital images have been indispensable in our daily life. Also, through many image editing software, people can modify images conveniently. As a result, the authentication for the integrity of digital images becomes an important issue, which has attracted more and more attention in academia and industries [1–5]. Some typical techniques for image authentication have been studied, such as image forensic [2] and fragile image watermarking [3–5]. Image forensic can authenticate the suspicious image without any pre-processing on original image, but it leads to heavy computation complexity with low accuracy. Fragile image watermarking can achieve tampering localization and further content recovery, however, it should conduct data embedding into the original image before possible tampering.

Perceptual image hashing, also known as robust image hashing, is an effective technique for image authentication, which can convert an input image into a fixed-length short sequence [6–9]. The outputted short sequence is image hash that represents perceptual contents of the original image. As an ideal image hashing scheme, visually similar images should have the same hashes (i.e., perceptual robustness) and visually distinct images should have quite different hashes (i.e., discrimination). Hence, image hashing should be resistant to content-preserving manipulations, such as JPEG compression, filtering and scaling, and also should differentiate the maliciously tampered image and its original version. Obviously, with satisfactory performances of perceptual robustness and discrimination, image hashing can also be utilized for image retrieval.

In recent years, many research works have been conducted to study image hashing [10–33]. Many image transform were exploited to develop image hashing methods, such as discrete cosine transform (DCT) [10–12], digital wavelet transform (DWT) [13,14], discrete Fourier transform (DFT) [15–17], and Radon transform (RT) [18–20]. Fridrich and Goljian utilized DCT coefficients to design robust image hash function [10], however, it can't resist the rotation attack. The scheme [12] integrated principal DCT coefficients of the sampled blocks and their corresponding position information to generate robust features. After the compression with dimensionality reduction for the concatenated features, the final image hash was obtained. Venkatesan et al. presented an image hashing method by using the statistics of wavelet coefficients [13]. This method was robust to the operations of JPEG compression, median filtering and small angle rotation. But its performance was not satisfactory when rotation angle was relatively bigger. A secure image hashing scheme based on entropy and DWT was proposed in [14], which had excellent performance of tampering de-

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tection, but its classification performance should be further improved. The scheme [15] was good at perceptual robustness toward several digital operations, including moderate geometric transform and filtering, however, its performance of discrimination was not good enough. In the scheme [16], Qin et al. conducted image feature extraction through the non-uniform sampling on the magnitude matrix of Fourier coefficients on DFT coefficients. This scheme achieved a good trade-off between perceptual robustness and discrimination, but, was only robust to rotation with small angles. Lefèbvre et al. utilized RT to develop an image hashing scheme [18]. The classification performance of this scheme was acceptable. Wu et al. combined DWT and RT to design image hashing scheme in [19], and the robustness of this scheme was good, which was resistant to print-scan on the premise of sacrificing discrimination capability to some extent. Roover et al. utilized RT to construct a radial variance (RAV) of image pixels through dividing image into radial projections, and then the first 40 DCT coefficients of RAV vectors were transformed into image hash [20], which was robust against image rotation. But, the collision probability of this scheme was high.

Besides the methods using image transform mentioned above, some researchers considered matrix operations in the design of image hashing [21,22]. Kozat et al. viewed digital images as a series of linear operators and employed singular value decomposition (SVD) twice based on matrix invariants in [21]. In this method, a secondary image was derived by using semi-global geometrical characteristic, and then the spectral matrix invariants were further retrieved from the secondary image with SVD to calculate image hash, which was resistant to rotation with the risk of increasing misclassification. Non-negative matrix factorization (NMF) was widely utilized in the field of image processing, which can effectively maintain the essence of original image matrix. Monga and Mihcak were the first to introduce NMF into image hashing [22]. In their scheme, NMF were applied twice to obtain the matrix approximation with dimensionality reduction, and the matrix entries were then concatenated to generate NMF-NMF vectors and output the final hash. This hashing scheme can be resilient to many common image manipulations, but was somewhat vulnerable to watermark embedding. A robust image hashing scheme based on ring partition and NMF was proposed in [28]. This scheme divided an original image into different rings with equal area and used them to form a secondary image invariant to rotation. Through this way, the secondary image also had fewer columns than the original image, and each column of the secondary image can be considered as a high-dimensional vector that can be further compressed with NMF to produce the compact hash. Some other effective techniques were also involved to realize perceptual image hashing, such as hierarchical histogram [23], error-diffusion based halftone [24], local binary patterns (LBP) [25], block truncation coding (BTC) [26], and invariant vector distance of statistics [29].

However, reported methods are mainly designed for gray-level images, and relatively fewer works focused on image hashing for color images. Color information is an important feature for images, and different colors of the objects in images may lead to the distinct semantics and understandings to users. Therefore, the hashing schemes considering color features of images deserve the in-depth investigated [27,30–32]. Quaternions (i.e., hypercomplex numbers) can be considered as a generalization of regular complex numbers, which consisted of one real part and three imaginary parts, and a quaternion with a zero real part was called as a pure quaternion [31]. Thus, each pixel in a color image can be represented with a pure quaternion, where the three imaginary parts indicated the red, green and blue components of the pixel, respectively, and by this way of hypercomplex representation, the RGB components of color images can be processed as a single entity, which effectively exploited color correlation during image processing. A robust hashing scheme for color images based on quaternion singular value decomposition (Q-SVD) was proposed by Ghouti in [32], in which the input color image after quaternion encoding was viewed as a quaternion matrix and the Q-SVD algorithm was twice conducted on the pseudo-randomly selected overlapping blocks to generate hash code using the left and right singular vectors associated with the largest singular values. Because Q-SVD can provide the best low-rank approximation of quaternion matrices for color images, thus, the generated hash code had some perceptual robustness. Laradji et al. utilized quaternion Fourier transform (QFT) that can be considered as a generalization of complex Fourier transform (CFT) in their color image hashing scheme [30]. The input color image was first resized and encoded with quaternions, then, after employing QFT on the quaternionic image, a binary sequence can be produced as the final image hash through thresholding the mean frequency energy of each block with the global mean frequency energy. In order to achieve better robustness, especially to large-angle rotation, Ouyang et al. proposed a novel robust image hashing for color images based on the quaternion discrete Fourier transform (QDFT) and log-polar transform [31]. In this scheme, after pre-processing, during the procedure of feature extraction, the log-polar transform was first applied on the image, in which image rotation caused a cyclical shift along the angle axis. Then, the image in log-polar domain was conducted with QDFT (that was the discrete form of QFT). Because the magnitudes of QDFT frequency coefficients were invariant to rotation and low-frequency components of QDFT held the principal energy and information of the image, some magnitude coefficients of a square region from the low-frequency spectrum were selected as the extracted features after scrambling. Finally, the binary image hash can be generated according to the relationship of these scrambled, selected magnitude coefficients. This scheme offered a good sensitivity to the tampering of image contents and can achieve the excellent performance of robustness to common content-preserving operations. In 2016, Tang et al. attempted to use the local color feature to generate image hash [27]. The details and potential problems of this scheme are given in Section 2. In this work, we improve the performance of Tang et al.'s scheme [27] and propose a new image hashing scheme for color images.

In the rest of the paper, Section 2 briefly reviews Tang et al.'s scheme and analyzes its potential problems. The proposed image hashing scheme is detailedly described in Section 3. Experimental results and comparisons are given in Section 4. Finally, Section 5 draws a conclusion of the paper.

2. Related work

In this section, we first review a robust hashing scheme for color images proposed by Tang et al. in [27]. Then, the existing problems and potential improvement for this scheme are analyzed.

2.1. Main idea of Tang et al.'s scheme

The scheme [27] consists of three main steps. In the first step, original image was converted into a fixed size with the bi-cubic interpolation, and then, was filtered through a Gaussian low-pass filter. In the second step, color vector angle of the pre-processed image was calculated and the edge points were also detected with Canny operator to extract robust image features. Finally, according to a series of concentric circles with the same center of the image, color vector angles of edge points on the concentric circles were used to generate image hash after quantization. The hash length of this scheme was equal to the number of the used concentric circles.

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