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Improving digital image watermarking by means of optimal channel selection☆

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ABSTRACT

Supporting safe and resilient authentication and integrity of digital images is of critical importance in a time of enormous creation and sharing of these contents. This paper presents an improved digital image watermarking model based on a coefficient quantization technique that intelligently encodes the owner's information for each color channel to improve imperceptibility and robustness of the hidden information. Concretely, a novel color channel selection mechanism automatically selects the optimal HL4 and LH4 wavelet coefficient blocks for embedding binary bits by adjusting block differences, calculated between LH and HL coefficients of the host image. The channel selection aims to minimize the visual difference between the original image and the embedded image. On the other hand, the strength of the watermark is controlled by a factor to achieve an acceptable tradeoff between robustness and imperceptibility. The arrangement of the watermark pixels before shuffling and the channel into which each pixel is embedded is ciphered in an associated key. This key is utterly required to recover the original watermark, which is extracted through an adaptive clustering thresholding mechanism based on the Otsu's algorithm. Benchmark results prove the model to support imperceptible watermarking as well as high robustness against common attacks in image processing, including geometric, non-geometric transformations, and lossy JPEG compression. The proposed method enhances more than 4 dB in the watermarked image quality and significantly reduces Bit Error Rate in the comparison of state-of-the-art approaches.

1. Introduction

Millions of multimedia contents are daily generated and distributed among diverse social networks, websites, and applications fostered by the rapid growth of mobile devices and the Internet. Particularly noticeable is the current pace of creation and sharing of digital images, which are ubiquitously captured to record and show diverse aspects of our personal and social life. This poses important challenges in terms of transmission, storage, and especially the usage of these data, in which the copyright protection plays a crucial role. Unprotected images can be accessed, downloaded and reused by others illegitimately. As a consequence, personal images might be subject to commercial or other purposes by third parties without legally requiring the user consent. To avoid this kind of situations, efficient and robust techniques are especially required for digital image copyright protection and authentication.

Digital watermarking is one of the most widely used approaches to univocally authenticate the owner of a given image. This technique allows embedding the owner's information, a.k.a, watermark, into the host image so that it is ideally unobserved by the human eye. In an inverse process, the watermark is recovered from the embedded image to obtain the hidden information to determine its originality. Most of the research in the digital image watermarking domain revolve around two main concepts, namely, perceptibility and robustness. First, embedding a watermark into a given image implies an alteration of the latter one, which normally translates into an effective degradation of the quality of the host image (Chou & Liu, 2010; Xiang-yang, Chun-peng, Hong-ying, &

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Table 1
Theoretical comparison of highlight digital image watermarking approaches.

Method	Transform domain	Side information	Host image	Watermark	Key
Tsai [2007]	None	Embedding position	Color	BinImg	Support vector machine
Tsui [2008]	Fourier	Real component	Color	BinBitSeq	Spatiochromatic discrete Fourier transform
Fu [2008]	None	Reference watermark	Color	BinImg	Linear discriminant analysis
Chou [2010]	Wavelet	Block location	Color	BinImg	Just noticeable color difference
Niu [2011]	Contourlet	Block location	Color	BinImg	Nonsubsampled contourlet transform
Dejey [2011]	Wavelet	Original host image	Grayscale	BinBitSeq	Fan beam transform
Bhatnagar [2012]	Wavelet-SVD	Transform order	Grayscale	GrayImg	Fractional wavelet packet transform
Wang [2012]	Wavelet	Bit ordering key	Grayscale	BinBitSeq	Hidden Markov model
Xiang-yang [2013]	Fourier	Number of scambling	Color	BinImg	Least squares support vector machine
Tsougenis [2014]	Fourier	Frequency number	Color	BinImg	Quaternion image moments
Proposed	Wavelet	Block location	Color	BinImg	Optimal channel selection
BinImg: binary image		BinBitSeq: binary bit sequence		GrayImg: grayscale image	

Pan-pan, 2013). Thus, reducing the perceptibility of the watermark is the objective of most proposed models, which mainly apply to grayscale images, with very less recognized attempts in watermarking color images. Second, the watermark must be as robust as possible to resist common image processing operations (Su, Chang, & Wu, 2013; Tsai, Huang, & Kuo, 2011), so the owner information can be entirely extracted from the watermarked image. In addition to these, another important property typically sought in watermarking techniques is blindness. Fundamentally, the blind watermarking technique (Dejey & Rajesh, 2011; Nasir, Khelifi, Jiang, & Ipson, 2012; Nezhadarya, Wang, & Ward, 2011; Yamato, Hasegawa, Tanaka, , & Kato, 2012) is the most challenging type since they do not require the original image, the watermark, and reference image for the recovery process, conversely to semi-blind schemes (Bhatnagar, Raman, & Wu, 2012; Dadkhah, Manaf, Yoshiaki, Hassanien, & Sadeghi, 2014; Ganic & Eskicioglu, 2005; Song, Yu, Yang, Song, & Wang, 2008), which require the watermark and reference image, and non-blind models that require all of them (Song, Sudirman, & Merabti, 2012; Tsui, Zhang, & Androutsos, 2008). However, in most watermarking techniques, a secret key is required for the extraction process. This key may be presented in different forms and encode diverse kind of information, e.g., a permutation of the watermark image, locations of the watermarked blocks, color profiles of the host image, and among others.

In this work, the authors develop a color watermark method using the wavelet quantization technique from the existing grayscale watermarking approach (Huynh-The, Banos, Lee, Yoon, & Le-Tien, 2015; Huynh-The, Lee, Pham-Chi, & Le-Tien, 2014). In order to enhance imperceptibility and robustness, an optimal channel selection mechanism for color images is proposed. During the embedding process, both LH and HL wavelet coefficients of the host image are grouped into wavelet blocks for each color channel. The bits of the binary watermark image are securely shuffled and then encoded into the optimal channel wavelet blocks by modifying the value of their coefficients. To that end, an innovative color channel selection scheme is proposed here, which aims at minimizing the visual difference between the original image and the watermarked image. The robustness is controlled by a factor that weights the watermark strength in the host image. In the extraction process, an adaptive threshold calculated by the Otsu method is for classification of the detected bits to recover the watermark. Compared to existing approaches, the proposed research method has strengths of: (1) a color channel selection mechanism for the embedding process to obtain the impressive imperceptibility, (2) a factor describing the strength of the watermark to flexibly balance robustness and imperceptibility, (3) an adaptive Otsu threshold in the extraction process to accurately recovery watermark. Nevertheless, the proposed method is fragile with rotation variances due to the use of Wavelet transform in the image decomposition process and the payload capacity is constrained by the decomposition level. Providing a theoretical comparison between the proposed research with highlight approaches in the removal-attack resistance watermarking field is necessary and further summarized in Table 1.

The remaining of this paper is organized as follows. Section 2 introduces the state-of-the-art in the digital image watermarking domain. Section 3 describes the proposed watermarking scheme. Experimental results and their evaluation are presented in Section 4. Finally, conclusions are outlined in Section 5.

2. Related work

Watermarking techniques can be categorized into two classes based on the processing domain: spatial domain and transformed domain. In spatial domain techniques, the watermark is embedded by directly modifying pixel values or the histogram of the host image. Here, most studies focus on the relationship between the visual quality of the watermarked image and the payload capacity of the host image. For example, Reversible Data Hiding (RDH) is considered by Tian (2003) together with Difference Expansion (DE) (Tian, 2002) to discover extra storage space in images by searching redundancy in their content. In this line, Li, Zhang, Gui, and Yang (2013) proposed Difference-Pair-Mapping (DPM) for the RDH scheme to increase the payload capacity of the embedded watermark. This is performed by modifying the histogram of the host image, so high-frequency bins are expanded to carry new data. However, the embedded capacity of this method is not as high as expected, since only one pixel in a pixel-pair can be modified for the embedment process. A general scheme for RDH based on Histogram Shifting (HS) has been reported by Li, Li, Yang, and Zeng (2013) to increase the payload capacity and visual quality. In recent years, Prediction-Error Expansion (PEE) (Thodi & Rodriguez, 2007) has been used in watermarking schemes as an improvement of DE. Li, Yang, and Zeng (2011) presented an adaptive embedding mechanism for increment in capacity and a pixel selection technique for visual quality enhancement based on PEE. The efficiency of PEE is further improved by leveraging the spatial correlation among color channels, as shown by Li, Li, and Yang (2012). Concretely, it is shown that more data can be hidden in the host image by using gradient information to enhance the prediction accuracy.

Due to the shortcomings of watermarking in the spatial domain, i.e., perceptible changes in the original image or fragility to image processing operations, most image watermarking techniques operate on a more robust transformed domain. Commonly used transformations are the Cosine transform (Lin & Chen, 2000), Fourier transform (Tsui et al., 2008; Wang, Han, & J.-C. Huang, 2007; Xiang-yang et al., 2013), Contourlet transform (Luo, Wei, & Liu, 2013; Niu, Wang, Yang, & Lu, 2011; Song et al., 2008), Curvelet