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Efficient color image reversible data hiding based on channel-dependent payload partition and adaptive embedding

Bo Ou [a,c], Xiaolong Li [b], Yao Zhao [c,d,*], Rongrong Ni [c]

[a] *College of Computer Science and Electronic Engineering, Hunan University, Changsha 410082, China*
[b] *Institute of Computer Science and Technology, Peking University, Beijing 100871, China*
[c] *Institute of Information Science, Beijing Jiaotong University, Beijing 100044, China*
[d] *State Key Laboratory of Rail Traffic Control and Safety, Beijing 100044, China*

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ABSTRACT

Existing color image reversible data hiding (RDH) methods mainly focus on utilizing the similarity between color channels for performance enhancement, but seldom pay attention to the discriminate properties among them. So the payload in these methods is equally partitioned and indiscriminately embedded into each channel. In fact, the prediction-error histogram (PEH) is varied for different channels, and embedding more bits into the one with a higher peak value would be beneficial to the color image RDH. In this work, to better exploit the inter-channel correlation and further enhance the embedding performance, a novel color image RDH scheme based on channel-dependent payload partition and adaptive embedding is proposed. Specifically, the total payload is advisably partitioned and then embedded into each channel according to its PEH, such that the total embedding distortion is minimized. Besides, for a single channel, the adaptive embedding that utilizes the smooth pixels preferentially is adopted by using other channels for reference. Experimental results verify that the proposed method can yield a better performance than some state-of-the-art works.

1. Introduction

As multimedia technology develops, the issue of information security and intellectual property protection has raised great concern in the public over the last decades. The traditional way for multimedia protection is to encrypt the media into a meaningless format, such that third parties cannot read it except the authorized ones. However, the encryption cannot prevent hacking when the content is decrypted. To compensate this, reversible data hiding (RDH) is proposed to embed data into media in an imperceptible way, and allows users to completely recover both the embedded data and the original content. Since the marked media is very similar to the original one, it may not arouse the attackers' attention and thus avoid the malicious manipulation during transmission. RDH plays an important role in the sensitive scenarios, such as medical, military and judicial imagery, where even a small permanent distortion on the original content would lead to a potential risk for image misinterpretation.

Nowadays, RDH has been extensively studied. In literature, RDH methods are mainly based on the following techniques, such as lossless compression [1–9], difference expansion (DE) [10–14], histogram shifting (HS) [15–25], prediction-error expansion (PEE) [26–44], integer transform [45–49], etc.

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* Corresponding author at: Institute of Information Science, Beijing Jiaotong University, Beijing 100044, China. Tel./fax: +86 10 51688667.

E-mail addresses: Gomes19851019@gmail.com (B. Ou), lixiaolong@pku.edu.cn (X. Li), yzhao@bjtu.edu.cn (Y. Zhao), rrni@bjtu.edu.cn (R. Ni).

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Lossless compression based methods hide data by compressing the cover media, such that the original content can be represented in a smaller size and the saved space is embedded with messages. Fridrich et al. [1] proposed to compress the bit-plane of an image with the minimal redundancy. In their method, the least significant bit (LSB) plane is selected for compression as the corresponding compression introduces the least distortion on the image. Celik et al. [3] proposed a generalized LSB compression for RDH, in which the compression efficiency is improved by using the unused portions of image as additional information. However, the bit-plane correlation is usually weak and the direct compression on it may cause a large alteration on a pixel. So, the early compression-based RDH cannot provide a satisfactory performance as it yields a low capacity and poor image fidelity. Recently, Chang et al. [5] proposed to use the side match vector quantization for the digital compressed image to save the storage space. Qin et al. [6] further improved the vector quantization for the compressed images by using mapping optimization. Zhang et al. [7,8] combined the current techniques with the recursive compression to achieve the rate-distortion bound, and can obtain a significant improvement than the previous compression-based methods. Zhang [9] proposed an optimal rule of value modification under a payload-distortion criterion by using an iterative procedure.

DE is first proposed by Tian [10], in which the difference between two adjacent pixels is multiplied by 2 and then added by a binary bit. Here, the operation of multiplying an element by 2 is called expansion. At decoder, the hidden bit is extracted as the LSB of the expanded difference. Compared with the previous methods, DE is more efficient in terms of decorrelating ability, and can achieve an embedding rate as high as 0.5 bit per pixel (BPP) with a relative low distortion. To prevent the underflow/overflow problem, DE needs to employ a so-called location map to restore the locations of the pixels which may be out of the gray-scale range after expansion. Among various DE-based methods, a notable technique, proposed by Kamstra and Heijmans [12], is to sort the difference according the smoothness of its neighborhood. By such a sorting technique, one can only modify parts of pixels to create just enough capacity for a given payload. Nowadays, the sorting technique is widely applied and extended in RDH methods, and has been proved effective in distortion reduction, especially in the low capacity case.

HS is another simple yet effective way for RDH. Ni et al. [15] first proposed a HS method, in which the data embedding is based on the pixel-intensity histogram. In their method, the pixels with the peak value of histogram are used to carry bits, and other pixels are subtracted or added by 1. Because the marked histogram is just the shifted version of the original one. Once the locations of original peaks are known, the data recovery can be easily implemented. Besides, as a pixel is modified at most 1 in HS, the peak signal-to-noise ratio (PSNR) of the marked image versus the original one can be guaranteed over 48.13 dB. A variation of HS is to use the prediction-error histogram (PEH) instead of the intensity histogram. The PEH is sharper than the intensity histogram, so a much higher capacity can be obtained for the same amount of modifications by using the former one. Luo et al. [18] proposed to use the interpolation technique for more accurate prediction, and can obtain a better embedding performance than previous HS methods. Wu and Huang [20] proposed to improve the performance of HS for a high capacity by considering the embedding efficiency. Tsai et al. [21] proposed to construct the difference histogram by calculating the differences between a pixel and its left and upper neighbors. Li et al. [22] proposed a general framework for constructing the HS method, and introduced two novel HS schemes based on this framework.

Thodi and Rodriguez [26] first proposed the PEE technique by integrating DE with HS. In their method, an image is first predicted and then the generated prediction-error is employed as the embedding unit. According to the PEH, prediction-errors are classified into two categories: one is expanded in a similar way of DE for carrying bits, and the other is shifted by adding or subtracting a capacity-dependent threshold. Since PEE exploits more correlations in an image, it has an excellent performance in terms of capacity and distortion control. Hu et al. [28] proposed an effective location map to ease the burden of storage of the auxiliary information. Hong et al. [29] proposed to use the median edge detector predictor for prediction, and can obtain a high quality marked image. Sachnev et al. [30] proposed to sort the prediction-errors by the local variances, and can significantly reduce the distortion. Gao et al. [33] proposed to use the generalized statistical quantity histogram by computing the arithmetic average of differences, and thus ensure a stable RDH performance on different kinds of images. Li et al. [34] proposed to adaptively embed two bits into a smooth pixel, and thus can achieve a very high capacity with the relatively low distortion. Qin et al. [42] proposed to incorporate the inpainting technique to improve the prediction accuracy, in which the reference pixels are chosen adaptively according to the image content. Coatrieux et al. [41] proposed a dynamic RDH method which utilized the image classification process to adaptively identify the areas suitable for embedding, and can embed data even in a texture area. Lu et al. [43] proposed an edge sensing predictor to obtain more accurate prediction results, in which the prediction method is determined by analyzing the complexity of an image. Very recently, PEE based on the two-dimensional (2-D) histogram is explored by considering the high-order correlations of images. Ou et al. [44] proposed a pairwise PEE to embed data into prediction-error pairs in order to further utilize the local redundancy. Based on the 2-D PEH, more efficient 2-D mappings can be designed to achieve a less distortion than the 1-D methods.

Besides, another board class of RDH methods is based on integer-transform [45–48] in which several pixels are grouped as an unit and embedded with multiple bits. Coltuc and Chassery [45] first proposed an integer transform for RDH, in which the LSBs of a pixel pair are replaced by the hidden bits and can be losslessly recovered after modification. Weng et al. [46] proposed to use the invariability of a pixel pair to increase the compression rate of the resulted location map. Wang et al. [47] proposed a generalized integer transform to extend the integer transform to pixel blocks of arbitrary length. Generally, this type of methods can achieve a very high embedding rate with a low computation complexity.

While RDH on gray-scale images is well established, the associated research for color images has not received