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Guided filtering based color image reversible data hiding ☆

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ABSTRACT

In this paper, a color-image-dedicated reversible data hiding (RDH) algorithm is proposed to improve embedding performance by applying a guided filtering predictor and an adaptive prediction-error expansion (PEE) scheme. PEE-based RDH methods can be mainly separated into two stages for each channel embedding, i.e., pixel prediction and prediction-error histogram (PEH) modification. In our work, the inter-channel correlation is exploited at all stages of prediction and modification. Specifically, for predicting the pixels in the current channel with the guidance of pixels from other channels, a linear transform model from reference channels to the current channel is established and its coefficients are determined by the Laplacian minimization criterion. Then, to modify the PEH, an adaptive PEE embedding scheme is conducted by seeking the optimal parameters of the embedding bins and the complexity threshold to minimize distortion. The experimental results demonstrate the proposed method has better performance than the state-of-the-art, color-image RDH methods.

1. Introduction

Reversible data hiding (RDH) is a technique that is used to embed secret data into a cover image in an imperceptible way, and in the extraction procedure, to losslessly recover the embedded data and the original cover image from the marked image. Unlike the traditional data hiding technique, the cover images can be restored completely without any external information. And due to the reversibility of the cover image and the high similarity of the marked and cover images, malicious attacks can be avoided in the transition. Currently, RDH is being used extensively in many applications, such as the transmission of military, medical, and forensic images.

According to the framework of embedding strategy, RDH methods can be mainly grouped into following four categories: lossless compression based methods, difference expansion (DE) based methods, histogram modification based methods and prediction-error expansion (PEE) based methods.

The lossless compression based RDH was firstly proposed by Fridrich et al. [1], where a proper bit-plane with the minimum redundancy was compressed. However, due to the weak correlation within a bit-plane, it's difficult to provide a high capacity and low-distortion performance. Recently, Qin et al. [2] proposed an improved vector quantization method to compress images by using mapping optimization. Zhang et al. [3] combined various existing techniques with the recursive compression to achieve the rate-distortion bound.

DE was firstly proposed by Tian [4], where the redundancy was explored to achieve a high-capacity and low-distortion RDH approach by expanding the difference between the two neighboring pixels of pixel pairs. Later on, the expansion technique has been widely developed, such as generalized integer transform based [5] and simplified location map based DE methods [6].

The first histogram modification based method was proposed by Ni et al. [7], where the zero or the minimum point of the intensity histogram of an image was utilized and slightly modified to embed data into the image. Then, an interpolation technique based histogram modification method was proposed by Luo et al. [8] to improve the embedding performance, where the embedding manipulation was imposed on the prediction-error histogram rather than the intensity histogram directly.

Recently, PEE-based RDH methods, which can be regarded as an extension of both DE methods and methods based on the modification of histograms, have attracted the attention of RDH researchers. The first PEE-based RDH method was proposed by Thodi and Rodriguez [9], and they used the prediction error in PEE for expansion embedding instead of the difference value in DE. Unlike DE, which merely considered the correlation between two adjacent pixels, PEE uses a larger range of neighborhood for computing the local correlation. Following [9], two aspects of improvements

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have been developed in recent years. On one hand, many embedding schemes were proposed such as double-layered embedding [10], adaptive embedding according to the local complexity of to-be-embedded pixels [11], two-dimensional difference-histogram modification [12], two-dimensional pairwise prediction-error modification [13], general multiple histogram modification [14], and recently proposed pixel-value-ordering technique incorporated two-dimensional pairwise prediction-error expansion [15], etc. On the other hand, some PEE methods exploited advanced prediction techniques, including inpainting-assisted predictor [16], local edge sensing predictor [17], etc., to generate a steeper prediction-error histogram.

All of the above-mentioned publications have demonstrated the extensive development of RDH research, but most existing methods were designed for gray-scale images, with relatively few methods being dedicated to color images. Although all existing gray-scale RDH methods can be used directly on color images by separating the secret message into three equal segments and embedding each segment individually, channel by channel. However, due to the lack of knowledge about strong correlations among channels, a simple transplant from gray-scale images to color images definitely cannot reach their optimal embedding bound, and, intuitively, the embedding performance of a dedicated color RDH method ought to be better than the common methods. To exploit the correlations between each channel, a few color image RDH methods were proposed. Yang et al. [18] developed an integrated RDH method to achieve small prediction-errors in the color difference domain for color filter array mosaic images. Tseng et al. [19] proposed a clustering-based histogram modification method to embed secret message in the cover color image reversibly. Li et al. [20] proposed to improve the prediction accuracy by using the similar edge structures between different channels. Recently, the state-of-the-art color image RDH algorithm [21] was proposed to improve the embedding performance by using the strategy of channel-dependent payload partition and adaptive embedding. However, all existing proposed algorithms still do not sufficiently exploit the inter-channel correlations, especially in the procedure of prediction. There is still a lot of work to be done in order to exploit these correlations further.

In this paper, a guided filtering based RDH algorithm dedicated to color images is proposed to further exploit the correlation among each channel and improve the embedding performance through more precise prediction and through the use of an adaptive PEE scheme. Specifically, existing PEE methods mainly predict the values by a channel-independent predictor; however, in our work, the predictor is improved by a modified guided filtering predictor, which sets the other two channels as the guidance for linear model regression. In addition, in the procedure of payload partition, a simple and efficient payload partition scheme is proposed to adaptively assign the capacities for each channel according to the sharpness of their corresponding prediction-error histograms. The rest of paper is organized as follows. Section 2 introduces the general framework of adaptive PEE, which is employed in our method and extended to the strategy for color images. Section 3 describes the core algorithm of guided filtering and extend it to inter-channel guided filtering predictor. Section 4 introduces the implementations of the proposed embedding and extraction methods. Section 5 shows the experimental results and finally, Section 6 concludes this paper.

2. General framework for adaptive PEE

In this paper, we employ an improved PEE method combined with adaptive embedding and the selection of optimal expansion bins to embed a secret message, and the improved method was referred to as AO-PEE in [14]. Now, we present a brief description of the gray-scale image AO-PEE embedding procedure, which can be mainly divided into two steps:

2.1. Step 1: Generation of a prediction-error histogram

First, the pixels to be embedding in the cover image must be determined. In our algorithm, we apply double-layer rhombus embedding scheme, which was first proposed by Sachnev et al. [10]. Specifically, the cover image is divided into two parts denoted by white and black bricks as shown in Fig. 1, and half of the message is embedded into white pixels for first-layer embedding; for second-layer embedding, the other half of the message is embedded into black pixels. Due to the similarity of the embedding for each layer, here, we take the first-layer embedding for example. Based on this scheme, we collect a one-dimensional sequence, denoted by $\{I_k, k = 1, 2, \dots, K\}$, from the white pixels with a scanning order from left to right and from top to bottom. Note that K is the total number of collected pixels.

Next, a predictor is used to predict each white pixel according to its neighboring black pixels and their corresponding prediction values are denoted by $\{\widehat{I}_k, k = 1, 2, \dots, K\}$. Most existing algorithms apply a simple rhombus predictor, i.e., averaging the four nearest neighbors of I_k, to obtain $\widehat{I}_k$. Then their corresponding prediction-errors are calculated by

$$\{e_k, k = 1, 2, \dots, K\} = \left\{I_k - \lfloor \widehat{I}_k \rfloor, k = 1, 2, \dots, K\right\} \tag{1}$$

where $\lfloor\ \rfloor$ indicates a round down operation. Therefore, a prediction-error histogram (PEH) function h is generated by counting the distribution of each e_k.

2.2. Step 2: Embedding the message by the AO-PEE scheme

After the generation of PEH, message is embedded by modifying PEH. To better exploit the redundancy of the image, in many existing PEE methods, such as [14,21], various local complexity measurements were computed for each I_k according to its neighboring context. Here, without loss of generality, each specific measurement is collectively denoted by C_k. Then, once a pixel I_k whose corresponding complexity C_k is greater than or equal to a predefined threshold, denoted by T, has been identified, its value remains unchanged. If pixel I_k satisfies $C_k < T$, its value will be processed by modifying its corresponding prediction-error, e_k, as

$$e'_k = \begin{cases} e_k & \text{if } a < e_k < b \\ e_k + w & \text{if } e_k = b \\ e_k - w & \text{if } e_k = a \\ e_k + 1 & \text{if } e_k > b \\ e_k - 1 & \text{if } e_k < a \end{cases} \tag{2}$$

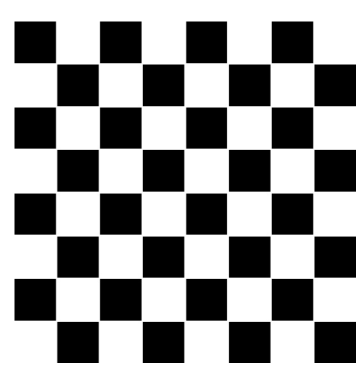

Fig. 1. Double layer rhombus embedding scheme. First layer embedding: one half message is embedded into white pixels, and second layer embedding: another half message is embedded into color pixels. For each layer embedding, the scan order is from left to right and from top to bottom.