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Reversible data hiding based on multilevel histogram modification and pixel value grouping ☆

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ABSTRACT

This paper proposes a multilevel histogram modification based reversible data hiding scheme using a new difference generation strategy called pixel value grouping (PVG). It aims to produce shaper difference histogram by exploiting the high correlation among pixels within block. After sorting, pixel values are grouped according to their distribution. For each set of similar pixel values, real or virtual reference pixel will be determined to compute differences in the scope of pixel values group and next secret message is embedded through expansion embedding. By PVG, we success to greatly reduce the number of to-be-shifted pixels while producing sufficient EC and hence less distortion can be introduced for embedding the same payload. Moreover, the same grouping can be achieved at the decoder and the real or virtual reference pixel can be determined without any prior knowledge, which guarantees the reversibility. Experimental results demonstrate that our scheme outperforms previous related state-of-the-art schemes.

1. Introduction

Data hiding [1] is a technique that embeds secret message into host media to ensure copyright protection, authentication, and so on. As an important branch of data hiding, reversible data hiding (RDH) develops very fast in recent years and has been applied to many quality sensitive fields such as military, medical imaging and remote sensing for the feature that marked image can be precisely recovered after message extraction. In general, the performance of RDH scheme can be evaluated by the embedding capacity (EC) and embedding introduced distortion.

Early RDH schemes mainly used lossless compression technique to create embedding space [2,3]. However, they cannot provide high EC while keeping distortion low. Later on, more efficient RDH schemes based on expansion and histogram modification technique have been devised. Difference expansion (DE) technique is firstly proposed by Tian [4] with the idea of embedding the secret message by expanding the difference between adjacent pixels. Although its EC is bounded by 0.5 bpp, DE based scheme can achieve better performance and thus has been widely investigated and developed in many aspects [5–8]. Nowadays, one of the extensions of DE called prediction error expansion (PEE) is commonly treated as the most effective RDH technique. Instead of the difference value in DE, the difference between pixel intensity and its predicted value computed from the context called prediction error is utilized for expansion embedding. As the local correlation of a larger neighborhood is exploited in PEE, better performance can be derived compared with DE. In this approach, better predictor always produces differences with smaller magnitude and hence embedding distortion can be reduced. Thus, many prediction methods are investigated for prediction accuracy improvement, such as median edge detector [8], rhombus prediction [9], interpolation techniques [10], gradient adjusted prediction [11] and partial differential equation [12]. Moreover, the PEE technique can also be developed in other aspects such as location map reduction [13], adaptive embedding [14,15], two-dimensional histogram modification [16,17] and pixel value ordering [18–20].

Besides DE, the histogram modification based scheme proposed by Ni et al. [21] is another remarkable work of RDH, in which the histogram bins between the peak point and zero point are shifted before the peak points are employed for data embedding. However, its EC is limited despite high marked image quality and low computational complexity. To construct a sharper histogram, Lee et al. [22] proposed to utilize the difference histogram instead and Tsai et al. [23] proposed to utilize the prediction error histogram. Afterwards, difference histogram modification is also adopted in many works [24–29] while the correlation of two adjacent pixels is considered in [24–26] and the correlation of pixels within block is considered in [27–29]. In [27], the host image is

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partitioned into several sub-images through sampling. Then one of them is selected as the reference image to compute differences with others and secret message is embedded by multilevel histogram modification (MHM). Luo et al. [28] improved Kim et al.'s work by selecting the median of each block to construct the reference image, which leads to a sharper histogram. Pan et al. [29] constructed local histogram for each block and the peak point is selected as the reference pixel to compute differences with other pixels. Moreover, only 1 and -1 are utilized for data embedding. MHM is also adopted in [26,30]. Zhao et al. [26] scanned the whole image of inverse "S" order to obtain a pixel sequence, and then the differences of adjacent pixels are computed. Compared with Zhao et al.'s, Fu et al.'s scheme [30] improved the differences concentricity around zero through prediction error histogram replacement.

Among above schemes, quite a few aim to create embedding space by exploiting block redundancy, which also can be expressed by high redundancy among pixels within block for their similar pixel values. For those schemes [18–20,27–29], sorting generally helps to utilize the correlation among pixels but their performance is still unsatisfactory compared with most PEE based schemes. For schemes in [27–29], all pixel values within block are modifiable except the reference one. Thus, lots of to-be-shifted pixels would be produced while processing blocks with loose distribution of pixel values. To reduce the number of to-be-shifted pixels, PVO-based schemes [18–20] proposed to modify the maximum and minimum only while others keep unchanged and serve for block complexity prediction. However, their EC is extremely limited. In this work, we focus on efficiency improvement in exploiting block redundancy and propose a new RDH scheme based on MHM and a new difference generation strategy. Unlike the previous schemes, we put forward the idea of pixel value grouping (PVG) and virtual reference pixel. After sorting, pixels with similar values of the maximum or minimum are respectively grouped into two modifiable sets. Then real or virtual reference pixel is determined to compute differences in the scope of pixel values group. By PVG, we can greatly reduce the number of to-be-shifted pixels while producing sufficient EC for two reasons. First, blocks with extreme distribution of pixel values are the only source of to-be-shifted pixels. Second, only the maximum and the minimum of those blocks can be chosen as to-be-shifted. As a result, the proposed scheme can well exploit block redundancy to achieve improved embedding performance. Experimental results show that the proposed scheme not only outperforms difference histogram modification based schemes [26,28,29], but also outperforms prediction error histogram based scheme [30] with moderate EC. This illustrates that reduction of to-be-shifted pixels is of great significance to RDH.

The rest of the paper is organized as follows. In Section 2, the related works are introduced. Section 3 presents the proposed scheme in details. Experimental results and performance comparisons with other schemes are shown in Section 4. Finally, we conclude the paper in Section 5.

2. Related work

In this section, we take Luo et al.'s scheme [28] as an example to introduce the details of multilevel histogram modification and how block spatial redundancy is exploited.

2.1. Summary of Luo et al.'s scheme

Suppose the host image I is a $M \times N$ gray-scale image. The data embedding process can be described with steps as follows.

Step 1. Image partition

Partition I into a set of non-overlapped $u \times v$ blocks.

Step 2. Reference pixel computation

For each block, retrieve all pixels to form a pixel array and sort all pixel values in ascending order such that $p_1 \leqslant p_2 \leqslant \cdots \leqslant p_{u\times v}$. Then the median is defined as the reference pixel p_{ref} which is used to compute differences with others.

Step 3. Block classification

Blocks are classified into four types: Type-I with $n_o = 1$, Type-II with $n_o \geqslant 2,\ n_l = n_r$, Type-III with $n_o \geqslant 2,\ n_l < n_r$ and Type-IV with $n_o \geqslant 2,\ n_l > n_r$, where $n_o,\ n_l,\ n_r$ represent the numbers of pixel values smaller, equal and larger than p_{ref} in a block, respectively.

Step 4. Difference computation and histogram construction

Compute the difference between p_{ref} and other pixels as

$$d_k = p_k - p_{ref} \tag{1}$$

where $1 \leqslant k \leqslant u \times v,\ k \neq ref$. Obviously $(u \times v - 1)$ differences will be obtained from each block and employed to construct a difference histogram. Assume the histogram bins are denoted by $b_{-255}, \ldots, b_0, \ldots, b_{255}$, respectively.

Step 5. Empty peak points

Before data embedding, bins in range of $[b_{-2\times EL-1}, b_{EL-1}]$ and $[b_{EL+1}, b_{2\times EL+1}]$ are emptied as

$$d_k^w = \begin{cases} d_k + (EL+1), & \text{if } d_k > EL \\ d_k - (EL+1), & \text{if } d_k < -EL \end{cases} \tag{2}$$

Step 6. Histogram shifting

Secret message is embedded by repeating Eq. (3) with $L = EL, EL-1, \ldots, 1$, respectively.

$$d_k^w = \begin{cases} d_k + (L+w), & \text{if } d_k = L \\ d_k - (L+w), & \text{if } d_k = -L \end{cases} \tag{3}$$

where $w \in \{0, 1\}$ is a data bit to be embedded. After that, process the differences with magnitude zero in Type-II block as

$$d_k^w = \begin{cases} d_k + (-1)^{q+1}, & \text{if } d_k = 0,\ w = 1 \\ d_k, & \text{if } d_k = 0,\ w = 0 \end{cases} \tag{4}$$

where q denotes the qth encountered d_k equaling zero. In a Type-III block, implement

$$d_k^w = \begin{cases} d_k - 1, & \text{if } d_k = 0,\ w = 1,\ q \leqslant n_r - n_l \\ d_k + (-1)^{q+1}, & \text{if } d_k = 0,\ w = 1,\ q > n_r - n_l \\ d_k, & \text{if } d_k = 0,\ w = 0. \end{cases} \tag{5}$$

In a Type-IV block, implement

$$d_k^w = \begin{cases} d_k + 1, & \text{if } d_k = 0,\ w = 1,\ q \leqslant n_l - n_r \\ d_k - (-1)^{q+1}, & \text{if } d_k = 0,\ w = 1,\ q > n_l - n_r \\ d_k, & \text{if } d_k = 0,\ w = 0 \end{cases} \tag{6}$$

Step 7. Image recomposition

The marked image is obtained as

$$p_k^w = p_{ref} + d_k^w \tag{7}$$

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