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Histogram-pair based reversible data hiding via searching for optimal four thresholds

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ABSTRACT

A histogram-pair based image reversible data hiding (RDH) scheme is presented in this paper. It embeds data into the prediction-errors generated from a cover image. In doing so, instead of changing a prediction-error x to $2x+b$ as done in most existing RDH algorithms, where b is a to-be-embedded binary bit, we modify the quantity x to $x+b$ so as to reduce the embedding distortion. Moreover, four thresholds, i.e., the embedding threshold, the fluctuation threshold, the right- and the left-end histogram shrinking thresholds, are employed and adjusted to achieve the highest PSNR at a given embedding rate. The experimental results have demonstrated that, comparing with the state-of-the-arts works, superior performance can be achieved by the proposed method. Particularly, by the proposed histogram shrinking, better embedding result can be achieved for the cover image with high peak bins at both sides of the image spatial histogram (e.g., the JPEG2000 test image Woman).

1. Introduction

In the past two decades or so, image reversible data hiding (RDH) has become an active research field. In the beginning of this century, the first a few RDH schemes based on modula-256 technique were reported [1], which can only embed a very small amount of data for the purpose of image authentication. However, although works, it suffers from salt-and-pepper noise [2] and the limited embedding capacity is not suitable for many other applications. Later, the least significant bit plane of a cover image [3] or the integer wavelet transform coefficients of a cover image [4,5] are compressed for RDH. But, the embedding capacity is still not high enough. To handle this issue, a scheme reported in [6] has largely boosted the payload of RDH in which one bit can be possibly embedded into each cover pixel quad, resulting in a larger embedding rate up to 0.25 bit per pixel (bpp). Then, a significant work based on difference expansion (DE) was reported in [7]. By DE, in the best case, one bit can be embedded into a pixel pair. Following [7], many improvements have been proposed and make RDH more efficient. Among these improvements, a good one is [8], in which the so called sorting technique is proposed to sort pixel pairs according to their local variances before data embedding. By manipulating image histogram to embed data, another effective scheme called histogram shifting (HS) was reported [9,10]. By HS, a good marked image quality is guaranteed with a sufficient high embedding capacity. Later on, some improvements of HS have been proposed [11–14] so the performance of RDH is further enhanced. Embedding data into prediction-errors is another significant progress of RDH [15–17]. In this way, the prediction-error histogram is firstly generated and RDH is implemented by modifying the generated prediction-error histogram. Nowadays, embedding data into prediction-errors is a major approach of RDH and many recent works follow this way. For example, a very good embedding result is obtained in [18] by using simultaneous sorting and prediction-error histogram manipulation.

Some advanced RDH schemes have been reported in recent years. In [19,20], the theoretical analysis of [21] has been moved further to achieve better performance in practical RDH. In [22], the method [20] is extended by considering a general distortion metric, and several new embedding methods either for gray or for binary image are presented. In [23], a general construction for designing HS-based RDH is proposed. In [24,25], instead of the conventional one-dimensional histogram, a two-dimensional histogram is exploited for data embedding. In [26], a dynamic histogram manipulation method is proposed in which each prediction-error is adaptively modified according to its local context. In [27], a multiple-layer data embedding mechanism is proposed. In a recent work [28], a multiple histograms generation and modification strategy is

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proposed and a good embedding performance is achieved for low capacity. In [29–31], by extending DE [7] from the viewpoint of integer transform, some new methods are also proposed.

In this paper, we focus on the RDH for gray images, and an efficient histogram-pair based image RDH method is proposed. The proposed method is realized by embedding data into the prediction-errors generated from a cover image. In doing so, instead of changing a selected prediction-error x to $2x+b$ as done in most existing RDH algorithms, where b is a to-be-embedded binary bit, we modify the quantity x to $x+b$ to reduce the embedding distortion. Moreover, four thresholds including the embedding threshold for determining the expanded bins, the fluctuation threshold for finding embedding locations with small variances, the right- and the left-end histogram shrinking thresholds for avoiding the overflow/underflow, are adjusted to achieve the highest PSNR for optimal data embedding. The embedding performance can be enhanced based on the four-thresholds-optimization, and the embedding capacity can be enlarged with the proposed histogram shrinking strategy. Notice that, the fluctuation threshold and the embedding threshold are simultaneously considered in our work to derive the best embedding performance, and it is different with the sorting technique proposed by Sachnev et al. [18] in which the sorting is actually independent of the embedding threshold. As a result, the proposed method performs better than [18]. Also, the proposed method utilizes fully enclosed neighboring pixels for prediction, which is helpful for performance enhancement as well. Here, to reduce the complexity in thresholds optimization, a double-round search strategy is proposed. That is, first, we conduct optimality search for two thresholds (the embedding and the fluctuation thresholds) at the same time fixing the other two. Then, for the two optimal thresholds in the first round search, we conduct optimality search for the other two thresholds (the right- and the left-end histogram shrinking thresholds). We conduct this type of procedure alternatively for multiple times to determine the four optimal thresholds. Experimental results on some commonly utilized images and one JPEG2000 test image (Woman) have demonstrated our superior performance. Particularly, by the proposed histogram shrinking, the embedding capacity can be improved, and for the cover image with high peak bins at both sides of the image spatial histogram such as the Woman image, better embedding result can be achieved compared with the state-of-the-arts works.

This work is an extension of our previously published workshop paper [12]. This paper, however, has included more analysis and provided more experimental works. The effectiveness of the proposed four-threshold optimization process has been thoroughly explained. The histogram shrinking strategy has been introduced in detail. The advantage of the proposed “$x+b$” embedding over the commonly used “$2x+b$” embedding has been further analyzed as well. Moreover, a distinguished feature of this paper is that, a strategy to achieve high capacity RDH has been proposed based on iterative embedding. For example, the highest embedding rate reported in [12] is 0.7 bpp, while the highest embedding rate here is 2.1 bpp.

The rest of this paper is organized as follows. The histogram-pair based reversible data embedding is described in detail in Section 2. Then, in Section 3, the determination procedure of the four optimal thresholds is thoroughly explained. After that, the experimental results are reported in Section 4. Finally, the paper is concluded in the last section.

2. Histogram-pair based RDH

To facilitate the illustration, some notations utilized in this paper are first listed in Table 1.

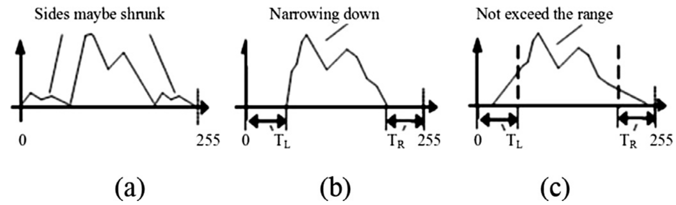

Fig. 1. Histogram shrinking. (a) Original (b) Shrunk histogram (c) After data embedding.

$g1$	$g4$	$g6$
$g2$	$\boldsymbol{g}$	$g7$
$g3$	$g5$	$g8$

Fig. 2. Local 3×3 window.

2.1. Histogram shrinking to avoid overflow and underflow

RDH in the prediction-error domain is much more efficient than that in the image spatial domain since the prediction-error histogram obey a Laplacian-like distribution [15]. However, it is hard to deal with the overflow/underflow when data embedding is conducted in the prediction-error domain. To this end, a histogram shrinking method is proposed in this paper to avoid overflow/underflow by shrinking the image spatial histogram before data embedding, i.e., the one or two sides of the image spatial histogram will be shrunken towards center (see Fig. 1 for illustration). Specifically, two non-negative integers T_L and T_R are set to shrink the image spatial histogram. Notice that, in the case of $T_L=T_R=0$, no pixel is modified in this pre-process. As an example, we give the detailed histogram shrinking process as follows for the case $T_L=1$. This process will be iteratively processed for T_L times if $T_L>1$.

In this process, we evaluate the following quantity to determine the optimally merged gray level g_L

$$g_L=\arg\min_{g}\{P_L(g)\} \tag{1}$$

where g is the gray level ranged from 0 to 255, and $P_L(g)$ is the left cost function defined as

$$P_L(g)=\sum_{i=g}^{g+1}h(i)+k\sum_{j=0}^{g}h(j),\quad 0\le g<255 \tag{2}$$

The first term of P_L is the number of bits needed for recording the locations of merged pixels (i.e., the locations of pixels with value g or $g+1$). The second term of P_L is the number of shifted pixels (i.e., each pixel value smaller than or equal to g will be increased by (1), and k is a cost parameter balancing the two terms and it is empirically taken as 2∼5 in our experiments. Notice that in (2), not only the cost of pixel merging, but also the cost of pixel shifting is taken into consideration. With this determined g_L, the gray level g_L is then merged to (g_L+1) from left edge of the image spatial histogram, and each gray level less than g will be increased by 1. The above process can be conducted in a similar way if $T_R>0$, and the routing detailed description is omitted.

2.2. Prediction by using fully enclosed neighborhood

In the proposed scheme, referring to Fig. 2, the prediction-error x is defined as the difference between the gray-value g and its estimated value derived from the eight neighbors,

$$x=g-\bar{g} \tag{3}$$