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Reversible image watermarking on prediction errors by efficient histogram modification

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ABSTRACT

A reversible data hiding algorithm is proposed, in which the efficiency of modifying a pair of histogram bins is considered. Multiple pairs of histogram bins can be further selected for data embedding in sequence, while pre-process of pixel values is performed to prevent the possible overflow and underflow. Embedding with the prediction errors is investigated with a new prediction scheme. In each of the four prediction modes, a large amount of prediction errors can be produced from the host image. Moreover, all combinations of the four modes to generate a number of histogram pairs are enumerated to obtain the best performance. Blind extraction and recovery are enabled by embedding a pre-computed location map and other overhead information into the watermarked image. Promising experimental results are obtained on a variety of test images. Compared with the existing algorithms, the image content is better preserved in high payload data hiding.

1. Introduction

In the literature, reversible data hiding has been extensively studied for digital images (e.g. [1–14]), audio (e.g. [15]) and video (e.g. [16]) signals, as well as 3D models (e.g. [17]). Also referred as reversible watermarking, the techniques of reversible data hiding are useful in those applications permitting no information loss, such as for medical and satellite images. There are several properties that a reversible watermarking algorithm should have, such as blind extraction, embedding capacity, and fidelity. In this paper, reversible image watermarking is focused and the host image before and after data embedding is called original and watermarked, respectively.

The existing methods for reversible image watermarking mainly utilize the techniques of lossless compression (e.g. [1]), circular interpretation of bijective transformation [2], difference expansion (e.g. [3–6]), integer-to-integer wavelet transform (e.g. [7,8]), histogram shifting (e.g. [9–14]), and so forth. A noticeable category of reversible data hiding method is by histogram shifting to empty a histogram bin for data embedding. In [9], the maximum and minimum points in the histogram are chosen as the embedding positions, which should be separately transmitted for extraction. A block-wise histogram modification algorithm is proposed in [10] by using the histogram of difference image. By using a binary tree structure to determine the difference values (0, ± 1, etc.) between the neighboring pixels, the side information is no more needed in [11]. Furthermore, the prediction errors are used in [12] to hide the secret data into medical images by histogram shifting. In [13], a new histogram-shifting based algorithm is proposed by employing the orthogonal projection to increase the prediction accuracy. Meanwhile, an interpolation technique is used to generate the prediction errors in [14] to improve the performance.

In the literature, the performance of a reversible watermarking algorithm is often evaluated in terms of embedding rate versus image quality measured by peak signal-to-noise ratio (*PSNR*) value. When the embedding

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rate is increased, more distortion will be introduced so that the image quality deteriorates. As the image content becomes less identifiable after a large amount of data are hidden, it is desirable to improve the quality of the watermarked image. In this study, a new reversible data hiding algorithm is proposed by considering the efficiency of modifying a pair of histogram bins and using it to guide the embedding process. To increase the embedding rate, multiple pairs of histogram bins can be selected in sequence and the pre-process is performed to prevent the possible overflow and underflow of pixel values. Embedding with the prediction errors is further investigated with a new prediction scheme. In each of the four prediction modes, a large amount of prediction errors can be produced from the host image. Moreover, all options of choosing a number of histogram bins with the four possible modes are enumerated to obtain the best performance. To extract the embedded data and blindly recover the original image, a pre-computed location map and other overhead information are saved into the watermarked image as well. Promising experimental results on a variety of test images are obtained. Compared with the existing algorithms, the image content is better preserved by the proposed one, especially for high payload data hiding.

The rest of this paper is organized as follows. Section 2 presents a new data embedding algorithm by taking the efficiency of modifying a pair of histogram bins into consideration. In Section 3, a new prediction scheme is designed to produce a large number of prediction errors from the host image, and embedding with the prediction errors is investigated. The experimental results are given and analyzed in Section 4. Finally, some concluding remarks are drawn in Section 5.

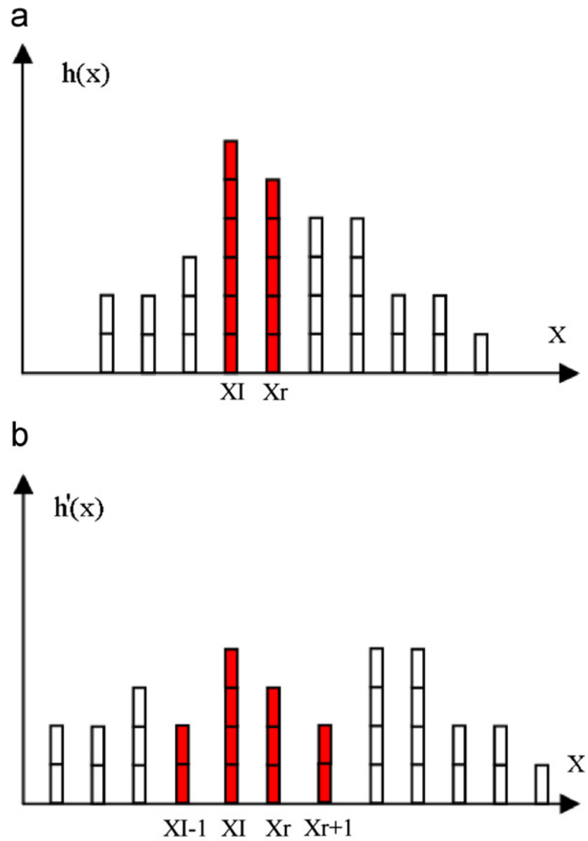

Fig. 1. An example of histogram modification for data embedding: (a) original histogram $h(x)$ and (b) modified histogram $h'(x)$ after data embedding.

2. A new histogram modification algorithm for data embedding

2.1. Considering the efficiency of histogram modification

Given a histogram $h(x)$, which represents the number of occurrence as the variable X assumes value x, it can be modified to embed a number of bit values in a lossless way. Here we assume that X only takes integer values. For a 8-bit graylevel image I, it can be a pixel value or a prediction error. Among the nonempty histogram bins, a pair of bins can be selected with the corresponding values x_l and x_r ($x_l < x_r$), as shown in Fig. 1(a) for instance. We use the histogram of pixel values to illustrate the embedding operations. For each pixel value x in the original image, the embedding operation can be performed by

$$x' = \begin{cases} x-1 & \text{if } x < x_l, \\ x_l - b & \text{if } x = x_l, \\ x & \text{if } x_l < x < x_r, \\ x_r + b & \text{if } x = x_r, \\ x+1 & \text{if } x > x_r, \end{cases} \tag{1}$$

where x' is the modified pixel value and b is the bit value to be embedded. Here we assume that no overflow or underflow occurs, i.e. all the modified pixel values are within the range of [0,255]. Normally, the number of histogram bins is increased by 2 after the embedding, as shown in Fig. 1(b) for instance. To extract the embedded data and restore the original pixel values, the selected bin values x_l and x_r need to be provided. Given a modified value x', the recovery operation is performed by

$$x = \begin{cases} x'+1 & \text{if } x' < x_l, \\ x' & \text{if } x_l \le x \le x_r, \\ x'-1 & \text{if } x' > x_r. \end{cases} \tag{2}$$

Meanwhile, the extraction operation is performed by

$$b' = \begin{cases} 1 & \text{if } x' = x_l - 1 \text{ or } x' = x_r + 1, \\ 0 & \text{if } x' = x_l \text{ or } x' = x_r, \end{cases} \tag{3}$$

where b' is the extracted bit value.

In the case as shown in Fig. 1, the two highest bins in the histogram are chosen so that the capacity of one pair embedding is maximized. However, the maximized capacity of one pair embedding does not ensure the best performance. As shown in Fig. 2, it may be more efficient to use the histogram bin x_e for data embedding instead of x_r. Although one more bit can be embedded with the bin x_r, however, more pixel values will be modified than using the bin x_e. When the number of modified pixel values is increased, the quality of host image will be affected.