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A high capacity reversible data hiding scheme based on generalized prediction-error expansion and adaptive embedding

Xinlu Gui, Xiaolong Li, Bin Yang*

Institute of Computer Science and Technology, Peking University, Beijing 100871, China

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ABSTRACT

In this paper, a high capacity reversible image data hiding scheme is proposed based on a generalization of prediction-error expansion (PEE) and an adaptive embedding strategy. For each pixel, its prediction value and complexity measurement are firstly computed according to its context. Then, a certain amount of data bits will be embedded into this pixel by the proposed generalized PEE. Here, the complexity measurement is partitioned into several levels, and the embedded data size is determined by the complexity level such that more bits will be embedded into a pixel located in a smoother region. The complexity level partition and the embedded data size of each level are adaptively chosen for the best performance with an advisable parameter selection strategy. In this way, the proposed scheme can well exploit image redundancy to achieve a high capacity with rather limited distortion. Experimental results show that the proposed scheme outperforms the conventional PEE and some state-of-the-art algorithms by improving both marked image quality and maximum embedding capacity.

1. Introduction

Reversible data hiding (RDH) aims to embed secret data into a host image by slightly modifying its pixels, and more importantly, the original image as well as the embedded message can be completely restored from the marked image [1–3]. The RDH technique has been widely applied to some sensitive application fields such as law forensics, medical image processing and military image processing. In general, the performance of a RDH algorithm is evaluated in the following three aspects: embedding capacity (EC), marked image quality and computational complexity. Specifically, for a given EC, one expects to minimize the embedding distortion and meanwhile keep the computational complexity as low as possible.

A significant amount of research has been done on RDH over the past few years. Early RDH algorithms are mainly based on lossless compression [4–9], in which certain features of host image are losslessly compressed to save space for embedding the payload. These methods usually provide low EC and may lead to severe degradation in image quality. Later on, more efficient algorithms based on histogram modification and expansion technique have been devised. The histogram-modification-based method is firstly proposed by Ni et al. in [10]. This method focuses on very high visual quality with quite limited EC, in which the peak point of image histogram is utilized to embed data. In this method, each pixel value is modified at most by 1, and thus the marked image quality is well guaranteed with a PSNR larger than 48.13 dB. The expansion technique is firstly proposed by Tian in [11] where the pixel difference is expanded to embed data. Compared with the

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* Corresponding author. Tel.: +86 10 82529693; fax: +86 10 82529207.
E-mail addresses: guixinlu@pku.edu.cn (X. Gui), lixiaolong@pku.edu.cn (X. Li), yang_bin@pku.edu.cn (B. Yang).

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compression-based RDH, Tian's method can provide a much higher EC while keeping the distortion low. Afterwards, the expansion technique has been widely investigated and developed, mainly in the aspects of integer-to-integer transformation [12–18], location map reduction [19–23], and prediction-error expansion (PEE) [24–32] where the difference value is replaced by the prediction-error in expansion embedding.

To the best of our knowledge, among existing RDH approaches, PEE usually leads to a good performance since it has a potential to well exploit the spatial redundancy in natural images. In conventional PEE embedding, after the prediction-error histogram is generated, high frequency bins are expanded to embed data while other bins are shifted to ensure the reversibility. Here, it should be noticed that each expanded prediction-error is uniformly embedded with 1 bit. In [33,34], unlike the conventional PEE, a data embedding level is adaptively adjusted for each pixel considering the human visual system characteristics. To this end, the just noticeable difference values are estimated for every pixel, and the estimated values as well as the edge information are used to determine the embedding level. Then, based on the embedding level, each pixel is adaptively selected for embedding with 1 data bit or shifting. Recently, the conventional PEE is improved by Li et al. [35] using adaptive embedding. As noisy pixels may cause much larger distortion than smooth ones with identical size of embedded data, the adaptive embedding in [35] guarantees that more data is embedded into a smoother pixel according to a local complexity measurement. Specifically, Li et al. first divide image pixels into “flat part” and “rough part”, and then, by using the conventional PEE twice or once, adaptively embed 2 bits or 1 bit into each expandable flat or rough pixel, respectively.

However, although the adaptive embedding in [35] plays an important role in improving the conventional PEE, this strategy can be further exploited to achieve a better performance. Since image pixels are simply classified into two categories for embedding 2 bits or 1 bit in [35], the performance improvement is limited. Based on this consideration, by further exploiting the adaptive embedding strategy and by extending the conventional PEE to a general form, we propose in this work a new RDH scheme which significantly outperforms the conventional PEE.

We first generalize the conventional PEE with an adjustable parameter k such that it can embed $\log_2(k+1)$ bits into a pixel. The generalized PEE includes the conventional PEE as a special case by taking $k=1$, and it is equivalent to using the conventional PEE twice if $k=3$. Then, instead of simply classifying image pixels into two categories in [35], we divide the pixels into several categories based on a partition of local complexity measurement, and embed more bits into a smoother pixel by taking a larger k in generalized PEE. The incorporation of adaptive embedding and generalized PEE provides a possibility to optimize the embedding performance. Actually, the complexity partition and the associated embedded data size of each pixel category are adaptively chosen for the best performance with an advisable parameter selection strategy. In this way, the proposed scheme can better exploit image redundancy to achieve a higher EC with less distortion compared with the conventional PEE and the adaptive embedding method of [35]. Experimental results also verify its superiority over some other state-of-the-art RDH algorithms.

The rest of the paper is organized as follows. The related work including conventional PEE and adaptive embedding is briefly introduced in Section 2. Section 3 presents the proposed RDH scheme in detail. The experimental results as well as the comparisons with the prior arts are shown in Section 4. Finally, Section 5 concludes this paper.

2. Related work

2.1. Prediction-error expansion

The embedding procedure of conventional PEE contains the following three steps:

1. According to a certain scanning order and by using a predictor, for each pixel x, determine its prediction value $\hat{x}$ and this value should be rounded off if it is not an integer. The prediction-error is denoted as $e=x-\hat{x}$.
2. Embed data by modifying the prediction-error histogram through expansion and shifting. Specifically, for each prediction-error e, it is expanded or shifted as

$$e^m=\begin{cases}2e+b & \text{if } -T\le e<T\\ e+T & \text{if } e\ge T\\ e-T & \text{if } e<-T\end{cases} \tag{1}$$

   where T is an integer-valued capacity-control parameter, and $b\in\{0,1\}$ is a to-be-embedded data bit. With (1), the bins in the inner region $[-T,T)$ are expanded to embed data, and those in the outer region $(-\infty,-T)\cup[T,+\infty)$ are shifted outwards to create vacancies to ensure the reversibility.
3. Finally, each pixel x is modified to $x^m=\hat{x}+e^m$ to generate the marked image.

In the above procedure, the maximum modification to image pixels is the capacity-control parameter T which is an important factor for the embedding performance. Therefore, to minimize the distortion in PEE, T is taken as the smallest positive integer such that the inner region can provide sufficient expandable pixels for embedding the required payload.

According to (1), after PEE embedding, prediction-errors belonging to $(-\infty,-T)$, $[-T,T)$ and $[T,+\infty)$ change to those in new intervals $(-\infty,-2T)$, $[-2T,2T)$ and $[2T,+\infty)$, respectively. The three new intervals are also disjointed with each other which guarantees accurate extraction and restoration of PEE.

The PEE extraction procedure can be summarized as follows:

1. For each marked pixel x^m, determine its prediction value $\hat{x}$. The marked prediction-error is thus $e^m=x^m-\hat{x}$. A key issue of PEE is that the prediction