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A novel reversible image data hiding scheme based on pixel value ordering and dynamic pixel block partition

Xiang Wang, Jing Ding, Qingqi Pei *

State Key Laboratory of Integrated Service Networks, Xidian University, Xi'an 710071, China

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ABSTRACT

Recently, various efficient reversible data-hiding schemes based on pixel value ordering have been proposed for embedding messages into high-fidelity images. In these schemes, after dividing the cover image into equal-sized blocks, the pixels within a given block are ordered according to their values, and data embedding is achieved by modifying the maximum and minimum values of each block. For a given embedding capacity, the optimal block size is exhaustively searched so that the embedding distortion is minimized. These pixel value ordering-based schemes perform fairly well, especially for low embedding capacity. However, to obtain a larger embedding capacity, a smaller block size should be used, which usually leads to a dramatic quality degradation of the marked image. In this paper, to address this drawback and to enhance the performance of pixel value ordering-based embedding further, a novel reversible data hiding method is proposed. Instead of using equal-sized blocks, a dynamic blocking strategy is used to divide the cover image adaptively into various-sized blocks. Specifically, flat image areas are preferentially divided into smaller blocks to retain high embedding capacity, whereas rough areas are divided into larger blocks to avoid decreasing peak signal-to-noise ratio. As a result, the proposed scheme can provide a larger embedding capacity than current pixel value ordering-based schemes while keeping distortion low. The superiority of the proposed method is also experimentally verified.

1. Introduction

Because of its ability to eliminate embedding distortion, reversible data hiding (RDH), also known as lossless data embedding, is increasingly attracting the attention of both academic and industrial researchers. The RDH decoder, unlike that of traditional data hiding schemes, can recover the cover image exactly as well as extracting the embedded data [3,24,31,40,41]. Therefore, RDH is usually used for copyright protection and data hiding of sensitive images, such as military and medical images. The performance of RDH schemes is evaluated on two conflicting criteria: embedding capacity (EC) and embedding distortion. In general, the goal of RDH is to minimize embedding distortion for a given EC.

Over the past few years, many different approaches have been proposed to improve RDH embedding performance. Examples include lossless compression-based algorithms [4,5,14,15], where the embedding space is produced by losslessly compressing a particular part of the cover image; the difference expansion (DE) technique [43], where the pixel difference is expanded to embed data; and the prediction-error expansion (PEE) technique [42], where the prediction error instead of the

* Corresponding author. Tel.: +86 29 88202927; fax: +86 29 88204909.
E-mail addresses: wangxiang@xidian.edu.cn (X. Wang), jding@stu.xidian.edu.cn (J. Ding), qqpei@xidian.edu.cn (Q. Pei).

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pixel difference is used for expansion embedding. In addition to hiding secret data in the spatial domain, another branch of reversible data hiding has been explored for use in the frequency or compressed domain, such as JPEG images [22,47] and vector quantization (VQ)-compressed images [8,25,32,46].

Recently, several PEE-based RDH methods, collectively called pixel value ordering (PVO) [28,37], have been proposed. In these methods, pixels within a block are ordered according to their values, and the prediction error expansion to hide data is calculated by using the second largest/smallest pixel to predict the maximum/minimum pixel. Because pixels in the same block usually have a strong correlation, these methods produce remarkable embedding performance. However, in PVO schemes [28,37], the cover image is divided into equal-sized blocks, and the PVO embedding performance is significantly related to block size. Using larger block size produces a sharper histogram, but obviously decreases EC. To achieve a higher EC, it is necessary to use a smaller block size, which usually results in significant image quality degradation. In addition, changing the block size causes a performance fluctuation on peak signal-to-noise ratio (PSNR), which is also experimentally demonstrated in the following sections (Fig. 5). For PVO-based schemes, determining the appropriate block size for a given EC is an important issue. Specifically, both of these PVO methods simply use exhaustive search to find the optimal block size.

This paper proposes a dynamic image-division strategy that extends PVO-based schemes to improve embedding performance, especially for relatively large EC. In the proposed method, instead of using equal-sized blocks, the size of each block is adaptively determined according to the context information and the EC. For a smaller EC, only smooth areas of the cover image are used to embed data, and a larger block size can be chosen. Compared with PVO-based methods, the proposed method performs better in most cases. To obtain a larger EC, data are embedded into both smooth and textured areas, but only smooth regions are divided into smaller blocks in the proposed method, and a larger block size can still be used in textured regions. Specifically, 2×2 and 4×4 blocks are used in smooth and textured regions respectively. Previous PVO-based methods divided the whole cover image (including both smooth and textured regions) into smaller blocks. Experimental results verify that the performance of the proposed method is superior to the Peng et al. method with optimal fixed block sizes and also to some state-of-the-art approaches; the superiority of the proposed method is more noticeable for large EC.

The structure of this paper is as follows. In Section 2, related studies, including lossless compression-based methods such as DE and PEE techniques, are briefly reviewed. In Section 3, the PVO-based scheme proposed by Li et al. [28] and its extension proposed by Peng et al. [37] are introduced in detail. The proposed improvement is presented in Section 4. The detailed implementation of the proposed method, including the embedding and extraction procedures and the treatment of underflow and overflow, is described in Section 5. Experimental results compared with those from PVO-based methods [28,37] and some state-of-the-art research are reported in Section 6. Finally, the last section presents conclusions.

2. Related work

Many RDH methods have been proposed in the literature. Early RDH methods used lossless compression algorithms to create a reversible embedding space [4,5,14,15]. However, these methods cannot provide a high EC even using multi-pass embedding. Tians DE technique [43], which can provide a much higher EC, is the cornerstone of most recent RDH methods. By using the pixel difference to embed data, DE takes better advantage of local correlations within the image than algorithms that directly use lossless compression algorithms. Because two pixels are used to embed one bit of data, the EC of DE is bounded by 0.5 bit per pixel (bpp). Alattar [1] and Wang et al. [48] generalized the DE technique to blocks of arbitrary size rather than pixel pairs by using reversible integer transforms. As a result, the EC is improved from DEs 0.5 bpp to almost 1 bpp. Another benefit of the integer transform is that it can be easily extended to transform domains, such as the DCT domain [7] and the wavelet domain [2,26]. Note that DE embedding can generate pixels with values smaller than 0 (underflow) or larger than 255 (overflow). These so-called overflow and underflow problems are inevitable in both Tians original DE technique and its extensions. The location mapping technique is widely used to restrict the embedded pixels to the range of $[0, 255]$. Usually, the location map is a binary matrix used to label the pixel pairs of the cover image. In the location map, 1 means that the corresponding pixel block can be used for embedding without causing overflow or underflow problems, and 0 indicates that using the pixel block may cause overflow or underflow. To ensure reversibility, the location map should be embedded together with the data and should be first extracted by the decoder to locate the pixel pairs carrying the hidden data. However, the location map usually occupies a huge portion of the embedding space even when compressed.

Inspired by Tians DE technique, Thodi et al. [42] used the prediction error instead of the pixel difference for expansion embedding. This expansion embedding technique is usually called PEE. The prediction error is the difference between the pixel and its predicted value computed according to the context. Compared with DE, PEE can take advantage of image correlation in a larger local image region to achieve better performance [6,11,13,19,20,44,45]. The classical PEE model includes two main steps: prediction and histogram shifting. In the latter, data hiding is achieved by expanding the histogram bins around 0, shifting the other bins to create vacant space. The performance of histogram shifting and data hiding depend strongly on the prediction results. A better predictor produces a sharper histogram, i.e., a histogram with higher bins around 0. As a result, with a better predictor, the PEE shifts fewer pixels for the same EC, and hence embedding distortion is reduced. Therefore, various efficient predictors have been proposed to improve PEE performance, such as MED (median edge detector, [42,50]), GAP (gradient adjusted prediction, [36,51]), SGAP (simplified GAP, [9]), rhombus prediction [39], PDE prediction