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Embedding capacity raising in reversible data hiding based on prediction of difference expansion

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ABSTRACT

Most of the proposed methods of reversible data hiding based on difference expansion require location maps to recover cover images. Although the location map can be compressed by a lossless compression algorithm, this lowers embedding capacity and increases computational cost during the procedures of embedding and extracting. The study presents an adaptive reversible data scheme based on the prediction of difference expansion. Since each cover pixel generally resembles its surrounding pixels, most of the difference values between the cover pixels and their corresponding predictive pixels are small; therefore, the proposed scheme gains from embedding capacity by taking full advantage of the large quantities of smaller difference values where secret data can be embedded. The proposed scheme offers several advantages, namely, (1) the location map is no more required, (2) the embedding capacity can be adjusted depending on the practical applications, and (3) the high embedding capacity with minimal visual distortion can be achieved. Moreover, the experimental results demonstrate that the proposed scheme yields high embedding capacity by comparing the related schemes that are proposed recently.

1. Introduction

In practice, much information is stored in digital form. Since digital media is easily replicated and subject to tampering, protecting content is a significant issue. Information hiding schemes have been widely used to protect the content of digital media. Information hiding schemes generally embed messages in cover media by modifying its content. The embedded messages can then be used as authentication codes for protecting copyrights or as secret data for sharing information. If the objective is secret communication, steganography (Chan and Cheng, 2004; Lee and Chen, 2010; Lee et al., 2010; Lee and Tsai, 2009; Tsai and Wang, 2007; Yu et al., 2005) is preferable; if the goal is copyright protection, watermarking (Chang and Lin, 2008; Lin, 2001; Qi and Qi, 2007; Wang et al., 2008) should be considered.

Permanent destruction of the cover media is generally inevitable even after the embedded media have been extracted. However, even minor distortion may be unacceptable in medical, military, and law enforcement applications. Hence, restoring cover media without distortion is a significant issue. In reversible data hiding, while the secret data is extracted from the stego-image, the cover image can be completely restored without distortion. The numerous reversible data hiding schemes proposed in the past decade (Barton, 1997; Celik et al., 2005; De Vleeschouwer et al., 2003; Fridrich et al., 2002) have had very limited embedding capacity. Tian (2003) proposed a remarkable reversible data hiding scheme based on difference expansion (DE) technique that can provide adjustable embedding capacity depending on a predetermined threshold. The Tian's scheme partitions the cover image into a series of non-overlapping pixel pairs, each of which consists of two neighboring pixels. A secret bit is then embedded using the difference expansion of each pixel pair. However, some expansion of a pixel pair may cause overflow or underflow when a secret bit is embedded. Additional information provided by a location map is needed to indicate whether each pixel pair is embedded. Theoretically, the Tian's scheme has an embedding capacity of 0.5 bpp (bit per pixel), but the size of the location map is half that of the cover image (0.5 bpp). That is, directly embedding a location map in the cover image leaves no extra room to convey the secret message. Hence, an efficient lossless compression algorithm is needed to compress the location map. However, when the location map is associated with a complex image, compression is difficult, regardless of the lossless compression algorithm used since the content of map is disordered.

Ni et al. (2006) developed a histogram-based data hiding scheme different from Tian's scheme. In their scheme, the search for the pair of peak and zero points from the histogram is performed first. The peak point refers to the most frequently occurring pixel value in the

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histogram. The zero point represents the pixel value with zero or minimal occurrences in the histogram. The secret data are embedded by shifting the pixel values located between the peak point and the zero point. The peak and zero points are extra recorded information; though the extra information can assist to extract secret data and restore original image, the overhead data cause the complexity management. In addition, the embedding capacity is limited by the number of peak points in their scheme.

Other studies (Alattar, 2004; Hyoung et al., 2008; Kamstra and Heijmans, 2005; Kim et al., 2009; Lin et al., 2008; Lou et al., 2009; Tai et al., 2009; Thodi and Rodriguez, 2007; Tsai et al., 2009; Tseng and Hsieh, 2009) have proposed modifications of the Tian or Ni et al. schemes to enhance embedding capacity or to reduce degradation of the stego-image. A DE-based scheme proposed by Alattar (2004) extended Tian's scheme by using the vector instead of the pair to improve embedding capacity. By expanding the mutual difference of k-bit pixels of vector, the $k-1$ bits secret data can be embedded; namely, embedding capacity is $(k-1)/k$ bpp. Thodi and Rodriguez (2007) proposed prediction-error expansion, another DE-based data hiding scheme in which the prediction value of a pixel is inferred by its surrounding pixels. The secret bit is embedded by expanding the difference between the pixel value and prediction value. In a single pass, a maximum embedding capacity of 1 bpp is possible.

Lin et al. (2008) proposed a novel histogram-based scheme which used a multilevel hiding strategy to obtain high capacity and low distortion. First, the cover image I of $M \times N$ is divided into several non-overlapping blocks and each block size is $m \times n$. The difference image $D_i(x, y)$ of size $m \times (n-1)$ is generated using $D_i(x,y) = |I_i(x,y) - I_i(x,y+1)|$, where $0 \le x \le m-1, 0 \le y \le n-2$, $0 \le i \le (M \times N)/(m \times n) - 1$. Next, the secret bits are embedded by histogram modification of difference image $D_i(x, y)$ for each block. Like the Ni et al. scheme, the peak and zero points of each block must be recorded to extract secret data and to restore each block. Overhead information (peak and zero points) is substantially larger than that in the Ni et al. scheme. In addition, the overhead information will be increased while a degree of hiding level goes up in their scheme. Tsai et al. (2009) devised a reversible data hiding scheme that combines predictive coding and histogram shifting methods. The original image is first divided into numerous blocks, each of which contains $n \times n$ pixels. The residual image is then generated by predictive codes generated from the difference values of the center pixel (called basic pixel) and its surrounding pixels in each block. Finally, the secret bits are embedded by histogram modification method. However, overhead information is also large due to the large quantity of peak and zero points.

To recover the cover image without any distortion, we observe whether the extended reversible scheme is DE-based or histogram-based, overhead information is always needed for extraction and restoration. Embedding capacity (also defined as payload P) consists of overhead information O and secret data S, namely, $P = O||S$, where the symbol '||' indicates that bitstreams O concatenates S. Obviously, overhead information has a major effect on the actual embedding capacity (called pure payload). The lager O refers to the lower S can be carried.

Tseng and Hsieh (2009) proposed a prediction-based reversible data hiding scheme that does not require a location map for reversibility, *i.e.*, no substantial overhead information exists in their scheme. The receiver can completely extract the embedded message and restore the original cover pixel according to the difference value between the predictive pixel and the stego-pixel. However, the limitation in the number of difference values that can be used to carry secret bit restricts the embedding capacity.

In this paper, we present an adaptive prediction-based reversible data hiding scheme that improves the embedding capacity of Tseng and Hsieh's scheme, maintains high visual quality, and does not require a location map also. The secret message is embedded by expanding the difference value between the cover pixel and a corresponding predictive pixel. The predictive pixel is derived from the average of each cover pixel's surrounding pixels. Since each cover pixel generally resembles its surrounding pixels, most of the difference values between the cover pixels and their corresponding predictive pixels are small. The proposed scheme gains embedding capacity by taking full advantage of the large quantities of smaller difference values. The experimental results demonstrate that the proposed scheme achieves high embedding capacity with minimal visual distortion.

This paper is organized as follows. Section 2 reviews the reversible schemes developed earlier by Tian and by Tseng and Hsieh. Section 3 presents our proposed scheme. Section 4 compares the performance of the proposed scheme with that of other schemes in three aspects; *i.e*, (1) the hiding capacity can be adjusted, (2) the hiding capacity versus the image degradation, and (3) the amount of overhead information. Finally, conclusions are made in Section 5.

2. Related works

This section briefly introduces two reversible data hiding schemes. The first is the difference expansion technique proposed by Tian (2003). The second is the prediction-based reversible data hiding scheme proposed by Tseng and Hsieh (2009).

2.1. Difference expansion technique

Tian proposed a reversible data hiding scheme based on difference expansion. In Tian's scheme, the cover image is partitioned into a series of non-overlapping pixel pairs, each of which consists of two neighboring pixels. For an 8-bit grayscale image, a pixel pair (u, v) is used to embed a secret bit S, where $u, v \in Z$, $0 \le u, v \le 255$ and $S \in$. In the embedding phase, the difference value d and integer average value l are calculated by

$$d = u - v \text{ and } l = \left\lfloor \frac{u+v}{2} \right\rfloor.$$

The inverse transformation is

$$u = l + \left\lfloor \frac{d+1}{2} \right\rfloor \text{ and } v = l - \left\lfloor \frac{d}{2} \right\rfloor.$$

Next, the new difference value d' is obtained as follows:

$$d' = 2 \times d + s.$$

Finally, the stego-pixel pair (u', v') can be obtained by the following integer transform:

$$u' = l + \left\lfloor \frac{d'+1}{2} \right\rfloor \text{ and } v' = l - \left\lfloor \frac{d'}{2} \right\rfloor.$$

To prevent overflow and underflow, *i.e.*, to restrict $0 \le u', v' \le 255$, the absolute of new difference $|d'|$ after a secret bit S has been embedded must satisfy the following condition:

$$|d'| \le \min(2 \times (255 - l),\ 2 \times l + 1).$$

Therefore, a location map is needed to distinguish the status of every pixel pair whether it is expandable. However, the location map lowers embedding capacity and increases computational cost during the procedures of embedding and extracting.

In the extracting phase, an embedded secret bit S can be extracted by one least significant bit (LSB) of d', namely, $S = \text{LSB}(d')$. Meanwhile, the difference value d' and average value l' are computed as $d' = u' - v'$ and $l' = \left\lfloor (u' + v')/2 \right\rfloor$. The original difference value d is then restored as $d = \lfloor d'/2 \rfloor$. Finally, the cover pixel pair (u, v) can be obtained by $u = l' + \lfloor (d+1)/2 \rfloor$, $v = l' - \left\lfloor d/2 \right\rfloor$.