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An adaptive prediction-error expansion oriented reversible information hiding scheme

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ABSTRACT

Data hiding in digital images can be used in secure communication, copyright protection, and etc. For some important images, such as medical and military images, the original images must be recovered after extracting the embedded data, because distortions are unacceptable for these kinds of images. In this paper, we propose a reversible data hiding method based on prediction-error expansion. Each pixel of the cover image, excluding the first row and the first column, is predicted by its top and left neighboring pixels in the raster-scanning order. The relationship between the prediction error and the pre-determined threshold decides whether the current pixel is embeddable or not. Since the proposed prediction process provides small prediction error, our method can achieve high embedding rate and good visual quality of the stego image by the expansion of prediction error. During the procedure of extraction and recovery, the same prediction process is conducted, and then the embedded secret data and the cover image can be recovered correctly. The histogram squeezing technique is utilized to prevent underflow and overflow problems. Experimental results show that the proposed method provides better performance than some other methods.

1. Introduction

Information hiding, also named data hiding, is a technique that embeds information into the cover media, which has been widely studied in recent years (Petitcolas et al., 1999). The embedded information can be, for example, secret data for secure communication or the copyright information of the cover media for intellectual property protection. Text, audio, image, and video can all be utilized as the cover media. In this paper, we focus mainly on data hiding in digital images. Because the embedding procedure modifies the cover image, the digital representation of the content of the cover image will be changed. But for images in medical, military, and legal applications, even the modification of one bit cannot be allowed due to the risk of misinterpretations. To solve this issue, the concept of reversible data hiding was proposed, which means that, after the embedded data are extracted, the image can be completely recovered in its original form before embedding (Tian, 2003).

Reversible data hiding for digital images has been the subject of much research (Tian, 2003; Celik et al., 2005; Chang and Len, 2007; Chang et al., 2007; Ni et al., 2006; Alattar, 2004; Chang and Lu, 2006; Tai et al., 2009). Currently, there are two main categories of reversible data hiding methods, i.e., difference expansion based methods and histogram-shifting based methods. In 2003, Tian proposed a reversible data hiding method based on difference expansion (Tian, 2003). In his work, the cover image was divided into a series of non-overlapping, neighboring pixel pairs, and the difference of each pixel pair was doubled. Then, the doubled difference was either kept intact or changed according to the parity of the embedding secret bit. On the receiver side, the embedded secret data can be easily extracted from the least significant bit (LSB) of the differences of the pixel pairs in the stego image. But the additional information of the location-map was needed to solve the underflow and overflow problems. In 2006, Ni et al. presented a histogram-shifting based method to embed secret data reversibly (Ni et al., 2006). The peak point of the image histogram was selected and the pixel values in the range from its right one to the zero point were increased by one to create one vacant histogram bin for embedding. The number of secret bits that can be embedded was equal to the pixel number of the peak point in the histogram. However, the information of the peak point was required in the procedure of extracting the embedded data and recovering the cover image. To solve this problem, Tai et al. introduced a binary tree structure that can be used to pre-determine the peak point used for embedding messages (Tai et al., 2009). Consequently,

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the only information the sender and the receiver must share is the level of the binary tree.

Recently, the prediction-based reversible data hiding method, which is the extension of the difference expansion based method and the histogram-shifting based method, has been studied extensively (Thodi and Rodriguez, 2007; Tseng and Hsieh, 2009; Lee et al., 2010; Hong and Chen, 2011; Zeng et al., 2012). The key idea of the prediction-based method is that the prediction process is conducted first to estimate the cover image pixels, and the prediction error, i.e., the difference between the prediction result and the cover image, is used to embed the secret data by difference expansion or histogram shifting. Thodi et al. indicated that the cover image can be divided into its prediction result and corresponding prediction error (Thodi and Rodriguez, 2007). The predictor they used was a low-complexity algorithm with an inherent edge-detection mechanism (Weinberger et al., 1996). The prediction error was expanded according to the embedding data and combined with the prediction result to produce the stego image. The two methods in (Tseng and Hsieh, 2009; Lee et al., 2010) utilized neighboring pixels to predict each cover pixel during the scanning of the cover image, and the secret data were embedded by exploiting the expansion of the prediction error. Hong et al. tried several interpolation techniques, such as bi-linear interpolation and bi-cubic interpolation, to predict the cover image according to the chosen reference pixels and then shifted the histogram of prediction error to embed the secret data (Hong and Chen, 2011). As we know, in the prediction-based methods, a smaller prediction error leads to better visual quality of stego images and greater hiding capacity. Therefore, in this work, we propose a new prediction-based reversible data hiding method that achieves satisfactory performance through the use of an improved predictor and the embedding algorithm.

The rest of the paper is organized as follows. Section 2 describes the proposed reversible data hiding method. Experimental results and comparisons are given in Section 3, and Section 4 concludes the paper.

2. Proposed method

In our method, three neighboring pixels are utilized to predict each cover image pixel excluding the first row and the first column, and the prediction error is expanded to hide the embedding bits. Due to the small prediction error, the hiding capacity of the proposed method is high, and the quality of the stego image is satisfactory. Because the neighboring pixels for prediction are on the top and left of the current pixel and because the first row and the first column of the image are kept intact, the prediction error of the stego image is equal to that of the cover image. Therefore, the embedded bits can be extracted correctly, and the cover image can be recovered losslessly.

2.1. Embedding procedure

Because the pixels in the first row and the first column of the cover image are not used for embedding, we only conduct raster-scanning for the rest of the cover pixels, and the pixels in the first row and the first column are left unchanged. Denote $P(x, y)$ as the pixel value at the location (x, y) of the cover image P sized $M \times N$. For each scanned cover pixel $P(x, y)$, where $x = 2, 3, \ldots, M$ and $y = 2, 3, \ldots, N$, the following steps are implemented to hide the embedding bit:

Step 1: Eq. (1) is utilized to predict the current cover pixel value $P(x, y)$. The prediction value is denoted as $P'(x, y)$, and the prediction error, $d(x, y)$, is calculated using Eq. (2).

$$P'(x,y) = \begin{cases} \left\lfloor \frac{P(x,y-1)+P(x-1,y)+P(x-1,y+1)}{3} \right\rfloor & \text{if } 2 \leqslant y < N, \\ \left\lfloor \frac{P(x,y-1)+P(x-1,y)+P(x-1,y-1)}{3} \right\rfloor, & \text{if } y = N. \end{cases} \tag{1}$$

$$d(x,y) = P(x,y) - P'(x,y). \tag{2}$$

Step 2: The prediction result of each scanned cover pixel is divided into two cases according to the relationship between $d(x, y)$ and a pre-determined threshold T, see Eq. (3).

$$\begin{array}{ll} \text{Case I}: & \text{if } |d(x,y)| \leqslant T, \\ \text{Case II}: & \text{if } |d(x,y)| > T. \end{array} \tag{3}$$

Step 3: If the prediction error $d(x, y)$ matches Case I, the current cover pixel is judged as embeddable, and the current bit S for embedding can be hidden using Eq. (4).

$$P_s(x,y) = P'(x,y) + 2d(x,y) + S - 1, \tag{4}$$

where $P_s(x, y)$ is the modified value of the current pixel after embedding, and the embedding bit is $S \in \{0, 1\}$.

Step 4: If the prediction error $d(x, y)$ matches Case II, the current cover pixel is judged as non-embeddable, i.e., the current pixel is not embedded with any bit. The current pixel value $P(x, y)$ is then modified to $P_s(x, y)$ by Eq. (5).

$$P_s(x,y) = \begin{cases} P'(x,y) + d(x,y) + T, & \text{if } d(x,y) > T, \\ P'(x,y) + d(x,y) - T - 1, & \text{if } d(x,y) < -T. \end{cases} \tag{5}$$

After all the pixels in the raster-scanning order finish the above steps, the embedding bits can be hidden, and the stego image P_s is obtained. In the following, we give a simple example to illustrate the embedding procedure.

Fig. 1(a) shows one 3×3 cover image. Suppose that two binary bits for embedding are "1, 0" and that the pre-determined threshold T is set to 5. Because the first row and the first column are not used for embedding, the raster-scanning order of the cover image is: $P(2, 2) \to P(2, 3) \to P(3, 2) \to P(3, 3)$. The prediction value $P'(2, 2)$ of the cover pixel $P(2, 2) = 39$ can be obtained by $\lfloor (67 + 42 + 28)/3 \rfloor = 45$. The corresponding prediction error $d(2, 2)$ can be calculated by $39 - 45 = -6$, and its absolute value is equal to 6, which is greater than the pre-determined threshold $T = 5$. Therefore, the prediction error $d(2, 2)$ matches Case II in Eq. (3), and the pixel $P(2, 2)$ is non-embeddable. The modified value $P_s(2, 2)$ can be acquired by $45 + (-6) - 5 - 1 = 33$. In the same way, the prediction value of the next scanned pixel $P(2, 3) = 31$ can be calculated, i.e., $P'(2, 3) = \lfloor (39 + 28 + 42)/3 \rfloor = 36$, and the absolute value of its prediction error is equal to 5, i.e., $|d(2, 3)| = |31 - 36| = 5$, which is not greater than the threshold $T = 5$. Therefore, the prediction error $d(2, 3)$ matches Case I in Eq. (3). The current embedding bit "1" can be hidden using Eq. (4), and the modified pixel value $P_s(2, 3)$ can be obtained, i.e., $P_s(2, 3) = 36 + 2 \times (-5) + 1 - 1 = 26$. The two remaining pixels, $P(3,$

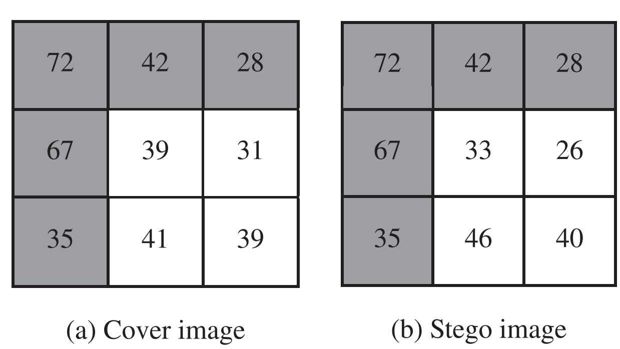

Fig. 1. An example of cover image and stego image.