A Data Hiding Method based on Multi-predictor and Pixel Value Ordering

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Abstract. Pixel Value Ordering (PVO) is a commonly-used method for reversible data hiding. PVO divides a cover image into non-overlapping blocks and the minimum and maximum values in a block are used to embed the secret data. The visual quality and embedding capacity of the PVO method is closely related to the size of the blocks. Thus, the proposed data hiding method utilizes the modified prediction methods and integrates with Ou and Kims method to improve the performance of the visual quality and embedding capacity. Pixel prediction not only can be used in restoring missing pixels but can also be utilized to realize data embedding. The proposed method adopts the MED, NMI, INP, and CRS pixel prediction methods to embed the secret data, because we found that different pixel prediction methods can provide different information.

Key words: Multi-predictor, reversible data hiding, sorted pixel values, predicted value

1 Introduction

Tian presented a reversible data hiding method by using the difference expansion strategy [14]. Tian's method pairs the pixels in the cover image and expends the pixel difference twice for the pixel pair. After that, the stego pixels are generated by using the expended difference value plus the secret data. At the receiver side, the secret data is extracted by taking the last bit of the stego difference value of the pixel pair. Further, Alatter presented a difference expansion based reversible data hiding method [1], which takes four neighboring pixels each time to embed three secret bits.

Sachnev et al. proposed a Prediction Error Expansion (also called PEE) data embedding method [12] to achieve the reversibility of the data embedding method. The main idea of Sachnev's method is to use four closest neighboring pixels to determine the sequence for data embedding. The main purpose of Sachnev et al.'s method is to enhance the visual quality of the stego image. Li et al. combined the characteristic of an image region and the PEE concept to classify the image region into a Flat region or Rough region to propose a reversible data hiding method [7]. Li et al.'s method creates a different embedding capacity in

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the Flat and Rough regions to achieve a good visual quality and embedding capacity. Furthermore, Gui et al. enhanced Li et al.'s method to create a reversible data embedding method [3]. Gui et al.'s method refines image region classification and assigns different embedding capacity to each image region type. Thus, Gui et al.'s method successfully improves the performance of the embedding capacity.

Histogram shifting is another commonly used reversible data embedding method. Ni et al. analyzed the pixel histogram of a cover image and embedded the secret data into the peak point pixel [11]. In Ni et al.'s method, the peak point and zero point information is retained for secret data extraction. After that, Wang et al. presented a reversible data embedding method [15] that uses the Markov Model to analyze pixel value distribution. Wang et al.'s method generates a histogram matrix and each cell in the matrix has different embedding capacity. Then, Chen et al. proposed a reversible data embedding method [2] by using the prediction error concept. Chen et al.'s method adopts the linear pixel prediction method to generate the maximum and minimum prediction error values that are used to generate the prediction error histograms. The different prediction error histograms use different embedding strategies to embed as much secret data as possible. Also, the stego image generated by Chen et al.'s method has good visual quality. Lu et al. proposed a reversible data embedding method [8] to improve Chen et al.'s method by combining Lukac prediction and Feng and Fan's prediction method to generate the maximum and minimum difference histograms. Also, the different histograms use different embedding strategies to embed the secret data.

On the other hand, Li et al. presented a data hiding method [6] by sorting pixels in a block and embedding the secret data into the pixel difference values. Li et al.'s main idea is that neighboring pixels have similar pixel value distribution, thus the difference between the minimum pixel and middle pixel and the difference between the maximum pixel and middle pixel are -1 and 1, respectively. Consequently, the data embedding capacity can be improved. Peng et al. proposed a pixel value ordering (PVO) based data embedding method [10] by modifying Li et al.'s pixel difference generation process. Peng et al.'s method subtracts a small value from a large value for pixel difference generation. Thus, the difference value will mostly fall on 0 or 1 to obtain a higher peak point (i.e. the embedding capacity can be improved). Wang et al. utilized dynamic pixel block partition strategy to segment the image and adopted an improved-pixel-value-ordering method to embed secret data into the cover image [16]. Ou and Kim proposed a pixel-based PVO (pixel value ordering) data embedding method [9] to embed more secret data into the cover image. Ou and Kim's method takes the maximum and minimum values from the adjoining pixels to embed the secret data.

As mentioned above, PVO, PPVO, and Wang's methods try to determine the maximum and minimum values from an image block. These methods achieve the goal of good visual quality for a stego image with acceptable embedding capacity. The PPVO method has a better data embedding capacity than others but the visual quality of the stego image can still be further improved. In this paper, a novel reversible data embedding method is presented. We are inspired by the Median Edge Detect, MED [17], Neighbor Mean Interpolation, NMI [4], Interpolation by Neighboring Pixels, INP [5], and High Capacity Reversible Steganography, CRS [13] methods to propose a data hiding method to further improve the embedding capacity and the visual quality of the stego image.

2 Related Works

2.1 Pixel-based Pixel Value Ordering (PPVO) [9]

To achieve high embedding capacity, Ou and Kim proposed the pixel-based Pixel-Value-Ordering (PPVO) method [9] to embed secret data into adjoining pixels. In PPVO, first, the current pixel $x_{i,j}$ is taken from an image block sized 4 × 4. Then, n neighboring pixels are taken from the block to form a reference set $C = \{c_1, c_2, \ldots, c_n\}$. The maximum and minimum reference pixels in C are chosen to embed the secret data using Eqs. 1, and 2.

$$x'_{i,j} = \begin{cases} x_{i,j} - s, \text{ if } x_{i,j} = C^{\min}, \\ x_{i,j} + s, \text{ if } x_{i,j} = C^{\max}, \\ x_{i,j} - 1, \text{ if } x_{i,j} < C^{\min}, \\ x_{i,j} + 1, \text{ if } x_{i,j} > C^{\max}, \\ x_{i,j}, \quad \text{otherwise }, \end{cases} \tag{1}$$

$$x'_{i,j} = \begin{cases} x_{i,j} + s, \text{ if } x_{i,j} = C^{\min} = C^{\max} = 254, \\ x_{i,j} - s, \text{ if } x_{i,j} = C^{\max} = C^{\min}, \\ x_{i,j} - 1, \text{ if } x_{i,j} < C^{\min} = C^{\min}, \\ x_{i,j}, \quad \text{otherwise }, \end{cases} \tag{2}$$

Where, $x'_{i,j}$ represents the stego pixel, s is the secret bit, and C^{max} and C^{min} are the maximum and minimum reference pixels in C, respectively.

2.2 Media Edge Detect (MED) [17]

Weinberger et al. presented a low computation cost median edge detection method [17] to effectively predict the missing pixel value located at the edge. The MED method uses a mask sized 2 × 2 to predict a suitable value for the missing pixel.

$$x_{i,j} = \begin{cases} \min(a, b), \text{ if } c \geq \max(a, b), \\ \max(a, b), \text{ if } c \leq \min(a, b), \\ a + b - c, \text{ otherwise}, \end{cases} \tag{3}$$

2.3 Data Hiding Method Using Image Interpolation (NMI) [4]

Jung and Yoo proposed a data embedding method [4] to embed secret data into an enlarged image. Jung and Yoos method translates an image block sized 2 × 2 into an image block sized 3 × 3 and fills the missing pixels in the gaps using interpolation (refer to Eq. 4).

$$P_{i,j} = \begin{cases} \lfloor \frac{x_{i,j-1}+x_{i,j+1}}{2} \rfloor, & \text{if } i = 2m, j = 2n+1, \\ \lfloor \frac{x_{i-1,j}+x_{i+1,j}}{2} \rfloor, & \text{if } i = 2m+1, j = 2n, \\ \lfloor \frac{x_{i-1,j-1}+P_{i-1,j}+P_{i,j-1}}{3} \rfloor, & \text{otherwise,} \end{cases} \tag{4}$$

Where m and n represent the height and width of the original image block.

2.4 Interpolating Neighboring Pixels (INP) [5]

Lee and Huang proposed a data embedding method [5] by using the difference value between the original pixel and the predicted values. First, the cover image is enlarged and the value for a missing pixel is calculated using the mean value and weighted computation from two closest neighboring pixels. The pixel prediction role is defined as shown in Eq. 5.

$$P_{i,j} = \begin{cases} \lfloor \frac{x_{i,j-1}+(x_{i,j-1}+x_{i,j+1})/2}{2} \rfloor, & \text{if } i = 2m, j = 2n+1, \\ \lfloor \frac{x_{i-1,j}+(x_{i-1,j}+x_{i+1,j})/2}{2} \rfloor, & \text{if } i = 2m+1, j = 2n, \\ \lfloor \frac{P_{i-1,j}+P_{i,j-1}}{2} \rfloor, & \text{otherwise,} \end{cases} \tag{5}$$

2.5 High Payload Reversible Data Embedding Method [13]

Tang et al. presented a data hiding method [13] that also adopts the pixel prediction strategy. Tang et al.'s method uses an image block sized 2 × 2 as one process unit and determines the maximum value (denoted as x^{max}), minimum value (denoted as x^{min}), and reference value AD from the block. Subsequently, the predicted value can be obtained by applying Eq. 7.

$$AD = \frac{3 \times x^{min} + x^{max}}{4} \tag{6}$$

$$P_{i,j} = \begin{cases} \lfloor \frac{AD+(x_{i,j-1}+x_{i,j+1})/2}{2} \rfloor, & \text{if } i = 2m, j = 2n+1, \\ \lfloor \frac{AD+(x_{i-1,j}+x_{i+1,j})/2}{2} \rfloor, & \text{if } i = 2m+1, j = 2n, \\ \lfloor \frac{x_{i-1,j-1}+P_{i-1,j}+P_{i,j-1}}{3} \rfloor, & \text{otherwise,} \end{cases} \tag{7}$$

3 The Proposed Method

3.1 The Prediction Phase

Since the proposed method uses the predicted values as reference data for the embedding procedure, the prediction phase combines the MED, NMI, INP, and

CRS methods to generate 16 predicted values. Pixels at the borders of a cover image are reserved, meaning that the pixels will not be used to embed the secret data. To easily describe the proposed method, the cover image is denoted as $X = \{x_{i,j} | i = 0, 1, \ldots, h-1; j = 0, 1, \ldots, w-1\}$ where h and w represent the height and width of the image X. $P_{MED} = \{p_i^{MED} | i = 1, 2, \ldots, 4\}$, $P_{NMI} = \{p_i^{NMI} | i = 1, 2, \ldots, 4\}$, $P_{INP} = \{p_i^{INP} | i = 1, 2, \ldots, 4\}$, and $P_{CRS} = \{p_i^{CRS} | i = 1, 2, \ldots, 4\}$ represent the predicted values generated by the MED, NMI, INP, and CRS methods, respectively. The prediction process uses a block sized 3×3 and the center pixel is the current pixel denoted as $x_{i,j}$. The prediction process is started from pixel $x_{1,1}$ and moves by one pixel at a time.

3.2 The Embedding Phase

After sixteen predicted values have been generated, all predicted values are collected to form the reference set $C = \{p_1^{MED}, p_2^{MED}, p_3^{MED}, p_4^{MED}, p_1^{NMI}, p_2^{NMI}, p_3^{NMI}, p_4^{NMI}, p_1^{INP}, p_2^{INP}, p_3^{INP}, p_4^{INP}, p_1^{CRS}, p_2^{CRS}, p_3^{CRS}, p_4^{CRS}\}$. Then, $C^{max} = \max(C)$ and $C^{min} = \min(C)$ values are chosen from the reference set C. The Eq. 1 is applied to embed the secret data. Fig. 1 shows a simple example for the proposed data embedding process. Pixels at the borders of the cover image X (shown in gray background color) are reserved, and the secret data is "10...". In the first block, the current pixel is $x_{1,1} = 52$, and the four corner pixels are $x_{0,0} = 55$, $x_{0,2} = 50$, $x_{2,0} = 51$, $x_{2,2} = 52$. After the prediction procession, the reference set $C = \{50, 55, 50, 55, 53, 54, 51, 50, 53, 54, 51, 50, 51, 52, 51, 51\}$ and $C^{max} = 55$, and $C^{min} = 50$. According to the embedding rule, $x_{i,j}$ is not used to embed the secret bit. Then the process block moves to the next pixel and $x_{1,2} = 50$, $x_{0,1} = 50$, $x_{0,3} = 50$, $x_{2,1} = 50$, $x_{2,3} = 50$. The reference set $C = \{50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50, 50\}$ is generated by applying the MED, NMI, INP, and CRS methods. According to the embedding rules, the current pixel $x_{1,2}$ will be changed to 49 to imply the secret bit '1'.

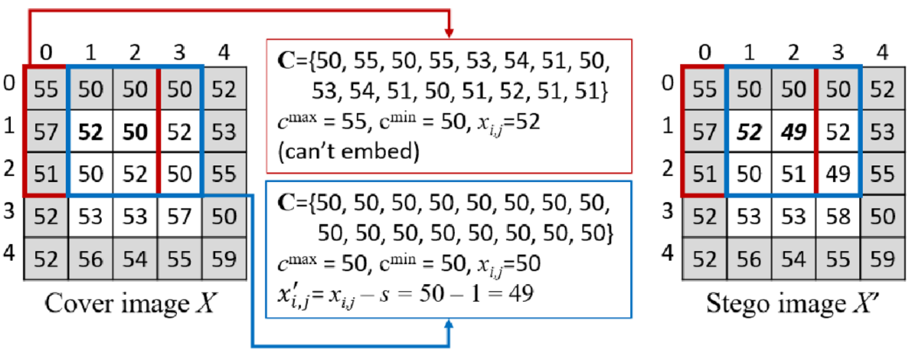


Fig. 1. A date embedding example

3.3 The Data Extraction Phase

The data extraction procedure is the reverse of the embedding phase. The data extraction process also takes a block sized 3×3 each time, starting from the last block in the stego image. For a stego block, the MED, NMI, INP, and CRS prediction methods are applied to generate the reference set C, c^{max} and c^{min}. Then, the secret bit can be extracted by using Eq. 8, and the original pixel can be restored by using Eq. 9.

$$s = \begin{cases} 0, \text{ if } \ x'_{i,j} = C^{max} \ \text{ or } \ x'_{i,j} = C^{min} \\ 1, \text{ if } \ x'_{i,j} = C^{max} + 1 \ \text{ or } \ x'_{i,j} = C^{min} - 1 \end{cases} \quad (8)$$

$$x_{i,j} = \begin{cases} x'_{i,j} + 1 \text{ if } \ x'_{i,j} < C^{min}, \\ x'_{i,j} - 1 \text{ if } \ x'_{i,j} > C^{max}, \\ x'_{i,j} \qquad \text{otherwise}, \end{cases} \quad (9)$$

3.4 Overflow and Underflow Handling

In cases where the pixel value equals to 255 or 0, then the stego pixel value might be changed to 256 or -1 after the embedding process. To avoid this situation, the proposed method will retain the pixel location information for the pixel whose value equals to 255 or 0. However, the pixel location information for pixels at the borders is redundant.

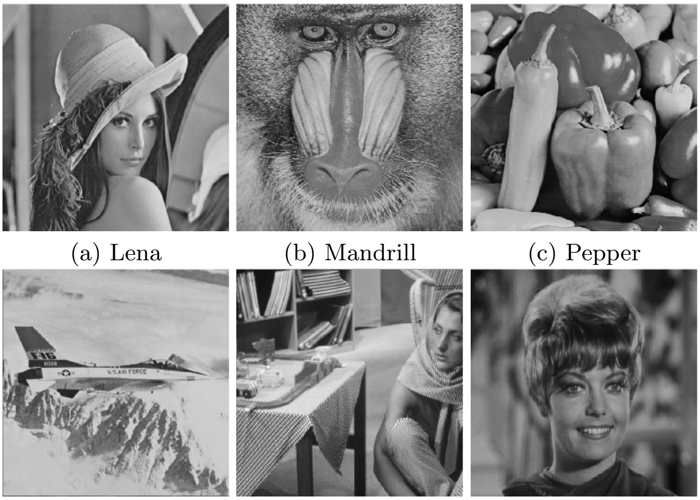
4 Experimental Results

Six test gray scale images were employed to be the test image (refer to Fig. 2). The visual quality and the embedding capacity are two most import factors for evaluating the performance of a data embedding method. To evaluate the visual quality of a stego image, which is generated by the proposed method, the Peak-Signal-to-Noise-Ration (PSNR) is adopted. The PSNR is defined as Eq. 10.

$$psnr = 10 \times \log_{10} \left[\frac{255^2}{\frac{1}{h \times w} \sum_{i=1}^{h} \sum_{j=1}^{w} (x'_{i,j} - x_{i,j})^2} \right] (\text{dB}), \quad (10)$$

where h and w are the height and width of the image, and $x_{i,j}$ and $x'_{i,j}$ represent the original pixel and stego pixel in location (i, j), respectively.

We set the parameters to the same as the PPVO method to compare the performance between the PPVO method and our proposed method. Table 1 summarizes the performance comparison of the proposed method using three and four prediction methods. In Table 1, using the NMI, INP, and CRS methods for data embedding, the proposed method can embed 5,000 to 10,000 more secret bit into a cover image than the PPVO (i.e., $n = 12$) method. In cases where four prediction methods are used in the proposed method, our visual quality is worse than the PPVO method at around 1 dB but we can embed more secret bits into a cover image than the PPVO method.



(a) Lena (b) Mandrill (c) Pepper

(d) Airplane (e) Barbara (f) Zelda

Fig. 2. The test images

Table 1. Performance comparison results (using three or four prediction methods)

Method		Lena	Mandrill	Pepper	Airplane	Barbara	Zelda
Propose Method (MED+NMI+INP)	Capacity	28,742	10,042	28,159	43,975	23,240	28,029
	PSNR	53.54	52.83	53.25	53.68	53.15	53.67
Propose Method (MED+NMI+CRS)	Capacity	29,655	10,332	29,090	45,135	24,264	29,626
	PSNR	53.40	52.67	53.09	53.53	53.01	53.47
Propose Method (MED+INP+CRS)	Capacity	28,857	10,071	28,259	43,959	23,446	28,526
	PSNR	53.18	52.77	53.19	53.61	53.11	53.60
Propose Method (NMI+INP+CRS)	Capacity	34,509	12,320	33,788	51,705	27,016	33,963
	PSNR	52.45	51.6	52.28	52.55	51.87	52.72
Propose Method (MED+NMI+INP+CRS)	Capacity	28,738	10,002	28,181	43,911	23,308	28,095
	PSNR	53.55	52.83	53.26	53.68	53.16	53.68
PPVO (n=12)	Capacity	24,195	7,564	20,224	37,317	19,503	22,561
	PSNR	53.98	54.89	54.27	54.27	54.23	54.09
PPVO (n=15)	Capacity	22,480	6,963	18,818	34,868	18,362	21,311
	PSNR	54.30	55.34	54.56	54.57	54.61	54.31

5 Conclusion

The proposed method utilizes multiple prediction methods to generate many predicted pixel values and incorporates Ou and Kim's PPVO data hiding technique to embed the secret data into a cover image. The experiment results show that the proposed method has better performance than other works in terms of embedding capacity and visual quality. In addition, the MED prediction method has good visual quality but the embedding capacity is limited. The proposed method uses the CRS method to obtain high embedding capacity with acceptable visual quality.

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