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Reversible image data hiding based on gradient adjusted prediction

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Abstract: The present study illustrates a new lossless data hiding method for digital images using image prediction technique. In the proposed method which is based on gradient-adjusted prediction (GAP), first prediction errors are computed and then the error values are slightly modified through shifting the prediction errors. The modified errors are used for embedding the data. Experimental results of present research have demonstrated that the proposed method called shifted gradient-adjusted prediction error (SGAPE) is capable of hiding more secret data with absolutely high PSNR.
Keywords: gradient-adjusted prediction, reversible data hiding
Classification: Science and engineering for electronics

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1 Introduction

In parallel with the development of information technologies, security becomes an important issue. Data hiding methods can conceal additional information in media. Most data hiding schemes distort the cover media in

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order to insert the secret data. Although the distortion is often small and imperceptible to human visual system, the reversibility is crucial to some sensitive applications, such as medical diagnosis, remote sensing and law enforcement. Therefore, it is desired to invert the marked media back to the original cover media after the hidden data have been retrieved.

Reversible data hiding is a novel category of data hiding schemes. For a survey on reversible methods, readers are referred to [1]. Ni et al. [2] introduced the lossless data embedding algorithm based on the spatial domain histogram shifting. In [3] a high capacity lossless data hiding method was proposed based on the relocation of zeros and peaks of the histogram of image blocks to embed the data. Recently, Lin and Hsueh [4] presented a reversible data hiding method based on increasing the differences between two adjacent pixels to obtain a stego-image with high payload capacity and low image distortion.

The proposed method, shifted gradient-adjusted prediction error (SGAPE), is based on increasing the differences between pixels of cover image and their prediction values. The prediction error at which the number of prediction errors is at a maximum is selected to embed the message. The prediction errors larger than the selected error are increased by "1". Furthermore, the selected prediction error is left unchanged and increased by "1" if the embedded bit is "0" and "1", respectively.

SGAPE method is able to embed a huge amount of data (15-140 kb for a $512 \times 512 \times 8$ grayscale image) while the PSNR of the marked image versus the original image is very high. In addition, simplicity, short execution time and applicability to almost all types of images make this method superior than most of existing reversible data hiding techniques.

2 The proposed method

SGAPE method contains embedding and extracting procedures. The embedding process includes both computing the prediction errors and embedding the information bits in the shifted prediction errors. However, the data extraction is the reverse of the data embedding. The proposed method is explained in the three following subsections.

2.1 The Prediction Algorithm

The gradient variations of the neighboring pixels are used for estimating the pixel value. The gradient-adjusted prediction (GAP) algorithm [5] operates on seven neighbors of the current pixel of a cover image $I_{i,j}$. By applying GAP prediction for $I_{i,j}$, its predictive value $\hat{I}_{i,j}$ can be computed as follows:

$d_h = |I_{i-1,j} - I_{i-2,j}| + |I_{i,j-1} - I_{i-1,j-1}| + |I_{i,j-1} - I_{i+1,j-1}|$

$d_v = |I_{i-1,j} - I_{i-1,j-1}| + |I_{i,j-1} - I_{i,j-2}| + |I_{i+1,j-1} - I_{i+1,j-2}|$

IF $(d_v - d_h > 80)$ {sharp horizontal edge} $\hat{I}_{i,j} = I_{i-1,j}$

ELSE IF $(d_v - d_h < -80)$ {sharp vertical edge} $\hat{I}_{i,j} = I_{i,j-1}$

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$\hat{I}_{i,j} = (I_{i-1,j} + I_{i,j-1})/2 + (I_{i+1,j-1} + I_{i-1,j-1})/4$

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IF $(d_v - d_h > 32)$ {horizontal edge} $\hat{I}_{i,j} = (\hat{I}_{i,j} + I_{i-1,j})/2$
ELSE IF $(d_v - d_h > 8)$ {weak horizontal edge} $\hat{I}_{i,j} = (3\hat{I}_{i,j} + I_{i-1,j})/4$
ELSE IF $(d_v - d_h < -32)$ {vertical edge} $\hat{I}_{i,j} = (\hat{I}_{i,j} + I_{i,j-1})/2$
ELSE IF $(d_v - d_h < -8)$ {weak vertical edge} $\hat{I}_{i,j} = (3\hat{I}_{i,j} + I_{i,j-1})/4$
}

The GAP predictor results in a new image with predicted pixel values.

2.2 Embedding

The embedding algorithm is as follows:

1) Prediction image is computed from the cover image by GAP algorithm (as described above).

2) The prediction error (PE) matrix elements are calculated by subtracting the predicted image from the cover image, $\mathrm{e}_{i,j} = I_{i,j} - \hat{I}_{i,j}$.

3) The number of prediction errors inside the interval $[\mathrm{d}, \mathrm{d}+1)$ is denoted by D(d). S value is found such that D(S) is at a maximum. As the GAP is a good predictor, in most images S value is equal to zero.

4) To prevent from overflow and error in extracting the embedded data, the position of all pixels with value 255 are recorded as side information. Also steps 5 and 6 are carried out for elements with $I_{i,j} < 255$.

5) In shifting stage, the modified PE matrix is derived from the PE matrix by this approach: For every $e_{i,j}$ $(i > 2$ *and* $j > 2)$, if $e_{i,j}$ is larger or equal to $S + 1$, then the modified PE $e'_{i,j}$ equals $e_{i,j} + 1$, otherwise $e'_{i,j} = e_{i,j}$.

6) In embedding stage, each $e'_{i,j}$ $(i > 2$ *and* $j > 2)$ inside the interval $[S, S+1)$ is increased by one if the corresponding bit of the data (to be embedded) is one, otherwise it will not be modified. After concealing data to $e'_{i,j}$, embedded PE $e''_{i,j}$ is obtained.

7) Finally, marked image pixel $I'_{i,j}$ is achieved by $I'_{i,j} = \hat{I}_{i,j} + e''_{i,j}$. If $I_{i,j} = 255$ then $I'_{i,j} = 255$.

In fact, the pixels in the two top-most rows and the two left-most columns of a cover image are preserved without carrying any hidden data. These rows and columns are the same in cover and marked images. Thus, the first pixel that can hold the secret message is at position $(3, 3)$ of the marked image and all scan processes in coder and decoder should start from this pixel. It is worth mentioning that in coder and decoder raster scan order is used. The gray value of S and position of all pixels with value 255 will be treated as side information that needs to be transmitted to the receiving side for data retrieval.

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2.3 Detection

The following process is used for extracting secret message from a marked image and lossless recovery of the host image and. Let the marked image $I'_{i,j}$ be the received image at the decoder.

1) As the pixels in the two top-most rows and the two left-most columns do not carry any secret data, we can readily restore them by $I_{i,j} = I'_{i,j}$ for $i = 1, 2$ or $j = 1, 2$. Beginning from pixel $I'_{3,3}$, the following steps (2-5) are performed for each pixel completely and then iterated for the next pixel. If $I_{i,j}$ was recorded as side information then $I_{i,j} = I'_{i,j}$ and steps (2-5) are performed for next pixel.

2) The prediction pixel value $\hat{I}_{i,j}$ of $I_{i,j}$ can be obtained by GAP algorithm with its seven adjacent pixels which have been already restored.

3) If embedded prediction error value, $e''_{i,j} = I'_{i,j} - \hat{I}_{i,j}$, is inside the interval $[S+1, S+2)$, then it is concluded that the embedded data bit is "1". In this case, $e''_{i,j}$ should be decreased by one to obtain modified prediction error value, $e'_{i,j} = e''_{i,j} - 1$. If $e''_{i,j}$ is inside the interval $[S, S+1)$, then the embedded data bit is "0" and $e'_{i,j} = e''_{i,j}$, Otherwise, there is no embedded data bit and again $e'_{i,j} = e''_{i,j}$.

4) If $e'_{i,j}$ is larger or equal to $S+2$ then prediction error value $e_{i,j}$ is calculated by decreasing $e'_{i,j}$ by one, $e_{i,j} = e'_{i,j} - 1$, otherwise $e_{i,j} = e'_{i,j}$.

5) Finally, the $e_{i,j}$ should be added to prediction value $\hat{I}_{i,j}$ to get original cover image pixel, $I_{i,j} = \hat{I}_{i,j} + e_{i,j}$.

Fig. 1 shows an example of a 5×5 grayscale image. The encoder scans the cover image in Fig. 1 (c1) pixel by pixel and subtracts the prediction pixels, Fig. 1 (c2), from the cover image pixels. In the prediction error matrix, Fig. 1 (c3), the S can be found which in this example, $S = 0$ and $\mathrm{D}(S) = 3$. The two top-most rows and the two left-most columns are not used for embedding. Suppose that the bit stream to be embedded is 101. The encoder scans the prediction error matrix and all values larger or equal to 1 are increased by one, Fig. 1 (c4). The elements obtained from the previous stage which are inside the interval $[0, 1)$ are chosen for embedding data. If the corresponding bit of the secret data is one, the modified prediction value is added by one, otherwise it will not be modified, Fig. 1 (c5). Marked image, Fig. 1 (c6), is obtained by adding embedded prediction errors, Fig. (c5), to prediction pixels, Fig. 1 (c2). As said before S, in this case equals to zero, is treated as side information.

It is already explained that the pixels with $i > 2$ *or* $j > 2$ are the same in marked and cover images. The decoder scans the marked image, Fig. 1 (d1), starting from pixel at position $(3, 3)$, and does all steps pixel by pixel as follows. Based on restored cover image pixels, Fig. 1 (d2), the prediction pixel value is computed, Fig. 1 (d3). If the embedded PE, Fig. 1 (d4), which is obtained by subtracting prediction pixel from marked image pixel, is inside

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4	3	5	5	6
3	4	4	6	7
2	1	2	5	3
4	4	3	2	3
7	4	5	6	3

(c1)

4	3	5	5	6
3	4	4	6	7
2	1	3	4.75	7
4	4	4	4.25	3
7	4	3	3.5	3

(c2)

0	0	0	0	0
0	0	0	0	0
0	0	-1	0.25	-4
0	0	-1	-2.25	0
0	0	2	2.5	0

(c3)

0	0	0	0	0
0	0	0	0	0
0	0	-1	0.25	-4
0	0	-1	-2.25	0
0	0	3	3.5	0

(c4)

0	0	0	0	0
0	0	0	0	0
0	0	-1	1.25	-4
0	0	-1	-2.25	0
0	0	3	3.5	1

(c5)

4	3	5	5	6
3	4	4	6	7
2	1	2	6	3
4	4	3	2	3
7	4	6	7	4

(c6)

4	3	5	5	6
3	4	4	6	7
2	1	2	6	3
4	4	3	2	3
7	4	6	7	4

(d1)

4	3	5	5	6
3	4	4	6	7
2	1	2	5	3
4	4	3	2	3
7	4	5	6	3

(d2)

4	3	5	5	6
3	4	4	6	7
2	1	3	4.75	7
4	4	4	4.25	3
7	4	3	3.5	3

(d3)

0	0	0	0	0
0	0	0	0	0
0	0	-1	1.25	-4
0	0	-1	-2.25	0
0	0	3	3.5	1

(d4)

0	0	0	0	0
0	0	0	0	0
0	0	-1	0.25	-4
0	0	-1	-2.25	0
0	0	3	3.5	0

(d5)

0	0	0	0	0
0	0	0	0	0
0	0	-1	0.25	-4
0	0	-1	-2.25	0
0	0	2	2.5	0

(d6)

Fig. 1. Embedding steps (c1) - (c6) and Detection steps (d1) – (d6).

the interval $[0, 1)$, the embedded data bit is "0" and modified PE is equal to embedded PE. In case the embedded PE is inside the interval $[1, 2)$, the embedded data bit is "1" and to get the modified PE, the embedded PE should be decrement. In order to get PE, Fig. 1 (d6), if modified PE is larger or equal to "2", it has to be decreased by one, and otherwise PE equals modified PE. Finally, restored cover image pixel, Fig. 1 (d2), is computed by adding PE, Fig. 1 (d6), to prediction pixel, Fig. 1 (d3).

3 Experimental results and evaluations

The Ni et al.'s [2], Fallahpour and Sedaaghi's (F&S's) [3], Lin and Hsueh's [4] and SGAPE algorithms was implemented and tested on various general test images of UWaterloo database [6].

The comparison between SGAPE and all methods mentioned in this literature proves that SGAPE method is capable of hiding more secret data than almost all compared methods at the same (above 40 dB) PSNR. The experimental results of SGAPE method show that the embedded data remains invisible, besides no visual distortion can be revealed. It is noteworthy that the embedded data was generated by the random number generator in MATLAB.

Table I, summarizes the experimental results obtained by SGAPE method. In Right Shifted type, interval $[0, 1)$ is used for embedding data and the prediction errors larger or equal to "1" are increased by one. In RL Shifted type, after right shifting, left shifting is used. In left shifting, the prediction errors smaller than "0" are reduced by one and interval $[-2, -1)$

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Table I. PSNR (dB) and payload (bits) of the test images of UWaterloo database.

Shift type		Right Shifted	RL shifted	RLR shifted	RLRL shifted
Lena	Payload	28971	57949	83937	108540
	PSNR	52.1	49.2	45.9	44.1
Barbara	Payload	23816	47363	68743	89296
	PSNR	51.9	49	45.5	43.7
Boat	Payload	28941	56850	82322	105900
	PSNR	52.1	49.2	45.8	44
Goldhill	Payload	20837	41466	60207	79110
	PSNR	52	48.9	45.4	43.5
Baboon	Payload	9629	19277	28584	37678
	PSNR	51.5	48.5	44.7	42.7
Peppers	Payload	22841	45669	66106	86373
	PSNR	51.9	49	45.5	43.6
Zelda	Payload	28906	57908	84636	110798
	PSNR	52.2	49.2	45.9	44.2

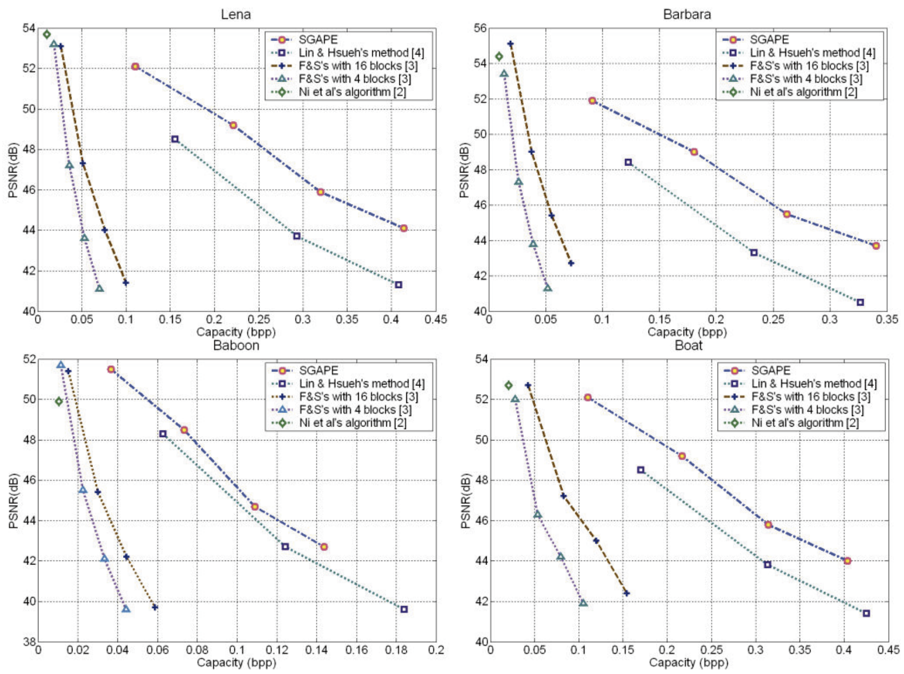

Fig. 2. Comparison among methods in [2, 3, 4] and SGAPE for Lena, Barbara, Baboon, and Boat images.

are used for embedding. The payload capacity is enhanced and the distortion is increased by increasing numbers of interval $[S, S+1)$.

Fig. 2 illustrates the performance comparison of SGAPE with the methods reported in [2, 3] and [4] for Lena, Barbara, Baboon, and Boat images in terms of PSNR and payload (bpp: bits per pixel). As shown in Fig. 2 SGAPE scheme provides high enough bound of the PSNR (above 40 dB) with a quite large data embedding capacity, indicating fairly better performance of SGAPE method. Fig. 2 confirms better performance of gradient-adjusted shifted prediction error method.

It is observed that this scheme provides high enough bound of the PSNR

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with a quite large data embedding capacity.

4 Conclusion

This paper presents a novel high-capacity reversible data hiding algorithm called shifted gradient-adjusted prediction error (SGAPE) which is based on shift differences between cover image pixels and their predictions. Large capacity of embedded data (15-140 kb for a 512×512 grayscale image), very high PSNR, applicability to almost all types of images, simplicity and short execution time are key features of this algorithm. Therefore, SGAPE method has advantages to the methods reported in [2] and [4] where used algorithms are considered as among the best methods in lossless data hiding.

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