Differential Direction Adaptive Based Reversible Information Hiding

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Abstract. In order to reversibly hide information in images with high capacity, an self-adaptive method is proposed in this paper by optimally selecting the differential direction. By dividing image into blocks, differences for adjacent pixel pairs in each blocks are computed in multi-directions. Based on the statistics of these differences, the optimal and self-adaptive strategy for increasing embedding capacity is introduced. The experimental results demonstrate that a significant improvement of embedding capacity is achieved, while the qualities of images is maintained.

Keywords: Reversible information hiding · High capacity · Differential direction

1 Introduction

With the rapid development of communication technology, internet has became one of the most important tools in our daily life. Internet information security becomes an increasing important issue with the widely application of internet. Individuals are worried about the safety of the information transmitted via the internet. In this scenario, information hiding technology attracts much attention and becomes one of the most popular research aspects in information security field, in recent years. As an important branch of the information hiding, reversible information hiding, which can extract the embedded data from the multimedia while restoring the original cover medium after data extraction, has widely applied in military, medical and the other fields. Due to the wide use and spread of digital images, the image reversible information hiding has become one of the hottest issues in multimedia content security, and more and more researchers focus on this topic.

In this decade, several impressive works are carried out and numerous significant algorithms are proposed. All of these reversible information hiding algorithms can be divided into several classes according to different standards. Considering the operation domain, reversible information hiding algorithms could be composed by embedding information in spatial domain, transform domain and compressed domain, for instance. The designers of these algorithms, without

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exception, try their best to balance the image quality, the capacity and the algorithm complexity. The reversible information hiding algorithms based on spacial domain, due to the low complexity, high capacity and good image quality, have been widely discussed and studied. The spacial algorithms are generally realized in three kinds of approaches:

(1) Lossless compression based algorithm. In these approaches, partial data of the cove image, LSB (Least Significant Bit) for instance, is lossless compressed, and the secret information is embedded as the redundancy. For example, Zhang *et al*. [1,2] proposed a method which claimed close to the optimal embedding performance, by compressing the features containing the vast majority of the energy in an image. In [3], Qian *et al*. proposed an algorithm which use 162 different variable length encoding methods defined in the JEPG for embedding messages. Higher capacity of this algorithm is achieved, when the higher compression rate is used, and as a result, a lower quality of the image is expected. To avoid commonly used LSB removal or replacement attack, Shabir *et al*. [4] used Intermediate Significant Bit Substitution (ISBS) to embed watermark data and checksum data, which is capable of providing high quality embedded images.
(2) Difference expansion based algorithm. Considering the correlation of adjacent pixels, the difference expansion based algorithms modify the differences of adjacent pixels to embed secret messages. A typical method is proposed by Tian [5] to embed data into adjacent pixel pairs, while Alattar [6] improves the capacity by using the pixel group with various dimension instead of pixel pair. Based on the difference expansion, Lee et al. [7] proposes an self-adaptive data embedding method, which select smooth areas to carry more information. Comparing with the other algorithms, this method have a better performance in capacity, while a location map is required, which is used to rebuild the cover image.
(3) Histogram shifting based algorithm. This kind of algorithms expands the value of pixels at the peak of the histogram, and uses the pixels, which are located among the zero and peak values, for shifting and furthermore for message embedding. Ni *et al*. [8] proposed to embed data into the interspace of the histogram in early phase. Hu *et al*. [9] constructed the Laplace-Like statistical histogram by prediction error. By shifting the Laplace-Like histogram, they received distinguishing results. Wang *et al*. [10] avoided the unnecessary pixels shifting by selecting the pixels according to the size of embedding data. In [11], Hwang *et al*. embedded messages into multi-pixels. They improved the capacity of the histogram shifting based algorithms, by using two different thresholds to select pixels to embed secret message. The thresholds are typically obtained according to the embedding capacity. Obviously, this method is a content adaptive algorithm, which means the capacity is unstable and highly related to the content of the cover image. Chen *et al*. [12] provided a new perspective of histogram shifting based reversible information hiding. They calculated multiple prediction errors for each pixel embedded data by combining the maximum and minimum error histograms.

Experimental result showed that embedding capacity is improved while the quality of watermarked images is maintained. As a recent work in [13], Lu *et al*. employed an edge sensitivity analysis method proposed in [14] before asymmetric-histogram shifting , to reduce the prediction error, and made it more suitable for both smooth block prediction and complex block prediction by expanding the edge sensitivity analysis method.

Lee *et al*. [15], Thodi and Rodriguez [16] and Weng *et al*. [17] proposed three new algorithms separately, by combining the difference expansion and histogram shifting. They believe the high coherence of the adjacent pixels in cover images, thus propose the difference histogram shifting based reversible information hiding methods. These methods markedly improved the embedding capacity because the peaks in the difference histogram are distinctly more than that in the original histogram.

In this paper, we focus on further improving the capacity of the difference histogram shifting based reversible information hiding algorithm. The paper is organized as follows. In Sect. 2, the previous difference histogram based algorithms are introduced. The proposed method, which is based on adaptive differential direction, is described in Sect. 3. The experiments are demonstrated and analyzed in Sect. 4. Finally the paper is concluded in Sect. 5.

2 Difference Histogram Shifting Based Algorithms

Considering the overflow in the embedding, the cover image have to be preprocessed in the difference histogram shifting based algorithms. A typical approach is as follows. For reversible information hiding based on difference histogram shifting algorithm, cover medium must be pretreated which can avoid overflowing when embed secret data. Cover image, which is denoted as I, is scanned into one dimensional sequences a vector $P = \{x_1, x_2, ..., x_L\}$, with the length of L. Pixels in the vector are modified according to Eq. (1), to generate a new vector $P' = \{x_1{}', x_2{}', ..., x_L{}'\}$, in which the range of pixel values is limited in [1,254] while the pixel values in P vary from 0 to 255. Meanwhile, the location map Q is generated and compressed using run-length coding. As a kind of header information, the location map Q is embedded into the cover image in conjunction with the secret messages.

$$x_i{}' = \begin{cases} x_i + 1, \ if \ x_i = 0 \\ x_i - 1, \ if \ x_i = 255 \\ \quad x_i, \quad else \end{cases}, \ Q = \begin{cases} 0, x_i \neq 0 \ and \ x_i \neq 255 \\ 1, x_i = 0 \ \ or \ \ x_i = 255 \end{cases}. \tag{1}$$

2.1 Information Embedding

We divide P' into two non-overlapping pixel pairs (p, q), with odd-index and even-index separately, and calculate the corresponding differences $D = \{d_1, d_2, ..., d_{L/2}\}$ between the pairs, according to $d_j = q_j - p_j, j \in [1, L/2]$. The secret messages are embedded by modifying the pixel pairs according to the differences. The algorithms of Lee *et al.* [15], Thodi and Rodriguez [16] and Weng *et al.* [17] could be described as Eq. (2–4).

$$Lee: \quad (\tilde{p},\tilde{q}) = \begin{cases} (p, \ q+1), & if D(j) > 1 \\ (p, \ q-1), & if D(j) < -1 \\ (p, q-M), & if D(j) = -1 \\ (p, q+M), & if D(j) = 1 \\ (p, \ q), & if D(j) = 0 \end{cases}. \tag{2}$$

$$Thodi: \quad (\tilde{p},\tilde{q}) = \begin{cases} (p, \ q+1), & if \ D(j) \geq 1 \ and \ odd \\ (p-1, \ q), & if \ D(j) \geq 1 \ and \ even \\ (p+1, \ q), & if \ D(j) < -1 \ and \ odd \\ (p, \ q-1), & if \ D(j) < -1 \ and \ even \\ (p+M, q), & if \ D(j) = -1 \\ (p-M, q), & if \ D(j) = 0 \end{cases}. \tag{3}$$

$$Weng: \quad (\tilde{p},\tilde{q}) = \begin{cases} (p-1, \ q+1), & if \ D(j) > 1 \\ (p+1, \ q-1), & if \ D(j) < -1 \\ (p+M, q-M), & if \ D(j) = -1 \\ (p-M, q+M), & if \ D(j) = 0 \ or \ 1 \end{cases}. \tag{4}$$

Obviously, Lee *et al.* [15] uses the pixel pairs with differences $D \in \{1, -1\}$ and Thodi and Rodriguez [16] selects differences $D \in \{0, -1\}$, to embed data M. Different from these two methods, the pixel pairs with differences $D \in \{1, 0, -1\}$ are chosen for embedding.

2.2 Information Extraction

For extracting the embedded data, the stego image is scanned into a vector P_N and also the differences $D_N = \{y_1, y_2, ..., y_{L/2}\}$ is generated, where $y_j = \widetilde{q_j} - \widetilde{p_j}, j = 1, 2, ..., L/2$. The different extraction methods [15–17] are explained in Eqs. (5) to (7).

$$Lee: M_N = \begin{cases} 1, if \ |D_N = 2| \\ 0, if \ |D_N = 1| \end{cases}. \tag{5}$$

$$Thodi: M_N = \begin{cases} 1, if D_N = -2 \ or \ D_N = 1 \\ 0, if D_N = -1 \ or \ D_N = 0 \end{cases}. \tag{6}$$

$$Weng: M_N = \begin{cases} 1, if \ |D_N| = 3 \ or \ D_N = 2 \\ 0, if \ |D_N| = 1 \ or \ D_N = 0 \end{cases}. \tag{7}$$

The extracted data M_N is divided into two parts: header information H and secret data m. To recover the cover image, the pixels should be shifted according to the differences D_N. And also, the under-flow and over-flow pixels could be recovered by the location map Q, which is assumed to be extracted as the header information.

Considering the capacity of the three approaches, Weng's method [17] advantages in the embedding capacity because the more pixels pairs with differences $D \in \{1, 0, -1\}$ are used, while simultaneously the quality of the stego image is relatively low. By using the pixel pairs with differences $D \in \{1, -1\}$ [15] and $D \in \{0, -1\}$ [16], a high visual quality and PSNR of stego image is guaranteed. Considering that the number of differences of 0 is bigger than the differences of 1, the embedding capacity of Thodi's method is higher than that of Lee's. Meanwhile, the modification of all pixel pairs in [16] results in a larger location map, compared with the even-index pixel modification in [15].

3 Differential Direction Adaptive Method

Considering the embedding capacity of difference histogram shifting method, the higher peak is in the difference histogram, the more bits could be embedded in the cover image. To our best knowledge, the previous approaches scan the images horizontally and furthermore obtain the difference histogram. Actually, the differences of pixel pairs denote the textures of the images. Therefore, different difference histograms are expected in differential direction, for various texture images. For instance, three difference histograms are obtained for Lena, using horizontal, vertical and Zig-zag scanning, as Fig. 1 demonstrated. The peaks in the histograms are 11621, 15041 and 10670 separately. This inspires us that the embedding capacity could be improved by generating difference histogram adaptively, according to the differential direction of the texture in the image.

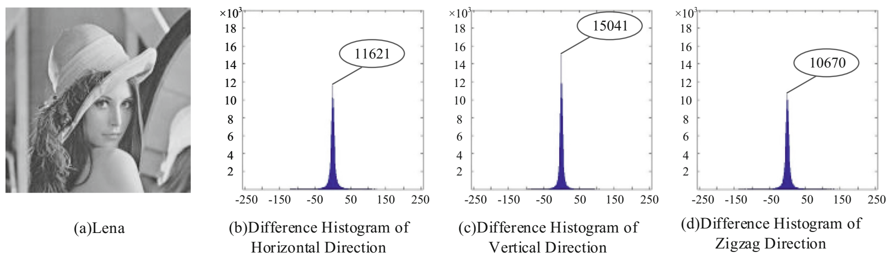

Fig. 1. Image lena and difference histograms: (b) horizontal; (c) vertical and (d) Zig-zag scanning.

In this paper, a differential direction adaptive approach is proposed to improve the embedding capacity by using several preset difference directions, according to the distribution of pixels in the cover image. In our method, four representative differential directions are introduced as follows.

(1) Horizontal direction: The image is scanned horizontally from the top to the bottom, as illustrated in Fig. 2(a).

(2) Vertical direction: We vertically scan the image from the left to the right, as illustrated in Fig. 2(b).
(3) Zig-zag direction: Similar with the Zig-zag scanning using in the JPEG coding, the image is scanned in diagonal direction, as illustrated in Fig. 2(c).
(4) Hilbert direction: Hilbert curve, which was proposed in 1891, can traverse all of the pixels in the image uniformly. Also the Hilbert curve shows the relativity between the neighbor pixels. Considering different origins, four Hilbert curve can be generated [18], as illustrated in Fig. 2(d) to (g).

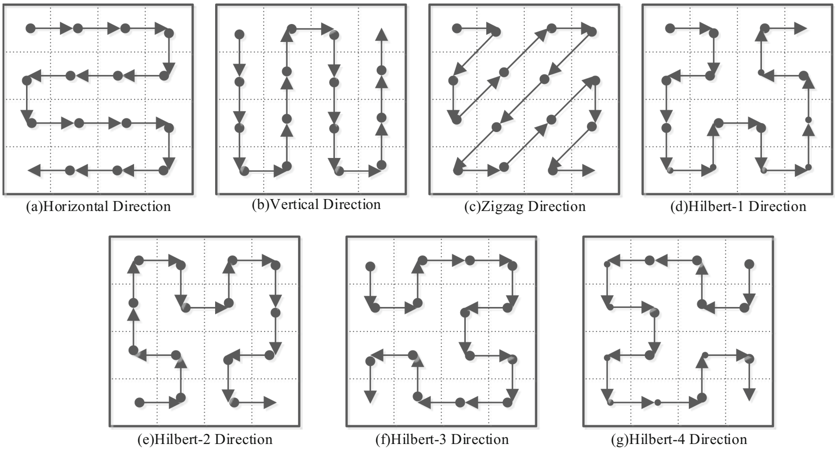

Fig. 2. Different scanning directions.

The differences along the four kinds of directions aforementioned could indicate the relativity in specific direction. For example, the horizontal coherence is enhanced in horizontal scanning, while the vertical and Zig-zag scanning could enlarge the vertical and diagonal correlation in the image. The Hilbert curve scanning balances the relativities in arbitrary direction. Therefore, the embedding capacity for the same image differs because of the different scanning directions.

For increasing the capacity, an intuitionistic approach is finding a specific scanning direction, which could obtain the maximum peak in the difference histogram of the cover image. Hence, we propose a new adaptive differential direction based method, which optimizes the scanning direction in each block of the cover image to achieve a higher embedding capacity.

The algorithm could be described as follows.

(1) Divide the cover image I into several $n \times n$ non-overlapping blocks.
(2) Each image block is scanned to seven vectors $P_i = \{x_1, x_2, ..., x_l\}, i = 1, 2, ..., 7$ with length $l = n \times n$, according to the pre-install seven kinds of difference directions, as Fig. 2 illustrated.

(3) Divide the pixels in the vectors P_i into two non-overlapping pixel pairs with length 1/2 and calculate their differences $D_i = \{y_1, y_2, ..., y_{l/2}\}, i = 1, 2, ..., 7$, where $y_j = x_{2j} - x_{2j-1}, j = 1, 2, ..., l/2$.

(4) The numbers of differences, -1, 0, and 1, which are used for embedding in these methods, are accumulated and denoted as S_a, S_b, S_c. Subsequently, the sum is calculated as $S_i = S_a + S_b + S_c, i = 1, 2, ..., 7$.

(5) The optimal scanning direction is selected by $S_m = max\{S_i\}, i = 1, 2, ..., 7$, where S_m obtain the biggest number of differences in i_{th} scanning direction.

(6) A scanning mode index vector is generated to record all of the optimal scanning directions in each image blocks. And also, the index vector is embedded into the cover image as a header information for extracting the embedded data.

4 Experimental Results

All of the experiments in this paper are carried out using MATLAB 2014a on a desktop computer. We evaluate the proposed method on 96 grayscale images of size 512 × 512, with the methods proposed by Lee *et al.* [15], Thodi and Rodriguez [16] and Weng *et al.* [17] as baselines. Figure 3 demonstrates samples of the test images. For each test images, the maximum Embedding Capacity (EC) and Peak Signal to Noise Ratio (PSNR) are calculated as the criteria to evaluate the performance of the reversible information hiding method. The PSNR is computed as Eq. (8) shows, where $M \times N$are the resolution of the cover image. The Mean Square Error, MSE is estimated by the pixels $I_0(i, j)$

Fig. 3. Four samples of the test images.

and $I_1(i,j)$, which are the values of the pixel located at i_{th} row and j_{th} column before and after embedding.

$$\begin{cases} MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (I_0(i,j) - I_1(i,j))^2 \\ PSNR = 10 \lg \left(\frac{255^2}{MSE} \right) \end{cases} . \tag{8}$$

In the experiments, each image is divided into six different sizes of blocks with resolutions of 512×512, 256×256, 128×128, 64×64, 32×32, and 16×16. Each block is processed by the proposed self-adaptive method to select the differential direction for information hiding, and a single fixed difference direction method is also carried out on the full size image as a baseline to show the validity of propose direction selecting method. Then the three aforementioned methods are applied to embed secret data in order to show the wide applicability of our method. The experimental results are demonstrated in Table 1.

Table 1. Average embedding capacity and PSNR of different block sizes

	Block size	Lee		Thodi		Weng	
		EC	PSNR	EC	PSNR	EC	PSNR
Differential direction self-adaption	512×512	11784	52.98	34455	51.92	40323	49.04
	256×256	11871	53.00	34750	51.92	40659	49.05
	128×128	11955	53.04	35160	51.93	41110	49.06
	64×64	12003	53.10	35656	51.94	41632	49.07
	32×32	12019	53.18	36387	51.96	42372	49.08
	16×16	12024	53.29	37518	51.98	43504	49.10
Single differential direction	512×512	11498	52.93	33417	51.90	39141	49.02

If we use a single fixed difference direction, for instance horizontal direction of difference, the difference of the cover image do not change with the size of block due to the single direction of difference. But for self-adaption difference direction, each block has different direction. With the decreasing of block size, the number of image block is increasing and the description of the texture direction in each block becomes more accurate. More pixels can be used to embed data, higher embedding capacity is expected. However, the complexity of computation also increases.

Experiments also show that the proposed method out-perform the single fixed difference direction method in the term of embedding capacity and PSNR, when the same information hiding strategy is used. As Table 2 demonstrated, the embedding capacity and PSNR is obviously higher than that of seven other difference directions, when the cover image is divided into 16 blocks with the size of 128×128. We can naturally get the conclusion that for the three different embedding methods, our self-adaptive difference direction method can im-prove the PSNR of the stego image and maintain, even improve the embedding capacity slightly. Compared with the horizontal direction of difference methods of Lee,

Table 2. Average embedding capacity and PSNR of different directions

	Lee		Thodi		Weng	
	EC	PSNR	EC	PSNR	EC	PSNR
Horizontal	11498	52.93	33417	51.90	39141	49.02
Vertical	11917	52.80	32923	51.88	38858	49.01
Zigzag	10674	52.60	29149	51.81	34458	48.93
Hilbert-1	11712	52.85	33170	51.89	38996	49.02
Hilbert-2	11713	52.85	33176	51.89	39004	49.02
Hilbert-3	11705	52.84	33163	51.89	38997	49.02
Hilbert-4	11700	52.84	33173	51.89	39001	49.02
Differential direction self-adaption	11955	53.04	35160	51.93	41110	51.93

Table 3. The best difference direction of partial test images

		Fishingboat	Lena	Protofino	Wood
Lee	Horizontal	22481	20307	14133	14005
	Self-adaption	25820	23288	16316	15529
	Growth rate	14.9%	14.7%	15.4%	10.9%
Thodi	Horizontal	23020	21703	14060	14527
	Self-adaption	26996	26724	16302	16225
	Growth rate	17.3%	23.1%	15.9%	11.7%
Weng	Horizontal	34445	31928	21143	20406
	Self-adaption	39894	38353	24414	22891
	Growth rate	15.8%	20.1%	15.5%	12.2%
Optimal difference direction in blocks		2, 2, 2, 2,	2, 2, 2, 2,	2, 7, 2, 2,	1, 5, 1, 2,
		2, 2, 2, 2,	5, 2, 7, 2,	2, 2, 2, 2,	6, 2, 7, 2,
		2, 2, 5, 2,	2, 2, 2, 2,	7, 2, 2, 7,	6, 2, 2, 4,
		1, 1, 6, 4	2, 2, 2, 2	1, 1, 5, 6	2, 2, 2, 2

Thodi and Weng, the self-adaptive difference direction method achieves a promotion of 4.0%, 5.2% and 5.0% in the term of embedding capacity, respectively.

Table 3 shows the optimal directions of all blocks in the sample test images, fishingboat, lena, portofino and wood, as shown in Fig. 3. All of these cover images are divided into 16 blocks with the size of 128 × 128 in this experiments. We explore the optimal difference directions automatically selected by the proposed method for all of the blocks. Number 1 to 7 in the last row of Table 3 denotes the horizontal, vertical, Zig-zag and four Hilbert curves scanning respectively. We can learn from the table that, it is not horizontal that most of the optimal difference directions in the 16 blocks are. Therefore, compared with the single fixed horizontal direction method, the embedding capacity of the proposed self-adaptive direction method significantly increases more than 10%, as shown in Table 3.

5 Conclusion

For the difference histogram shifting based reversible information hiding, a new self-adaptive method is proposed in this paper. By dividing the cover image into several blocks, optimal differential directions are selected to improve the embedding capacity and the PSNR of the stego image. Experimental results show that our algorithm maintains PSNR of the stego image, meanwhile improve the embedding capacity, compared with the baselines with single fixed difference direction methods.

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