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Reversible Data Hiding Based on Hilbert Curve Scan and Histogram Modification

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Abstract: As an effective technique, reversible data hiding played an important role in multimedia security. Its key advantage lies in not only the cover image but also the secret hidden data can be recovered accurately in decoder. In recent years, many reversible data hiding schemes for images were developed, aiming to enhance the hiding capacity and stego-image visual quality. Fractal curves have been successfully applied in digital image processing. In this study, the Hilbert curve, one of the popular used Fractal curves, was applied for reversible data hiding in natural images incorporated with histogram modification. Extensive experimental results demonstrated the effectiveness of the proposed scheme. Moreover, the superior performance of higher capacity and better stego-image quality is illustrated in comparison with several available methods of the same kind.

Key words: Reversible data hiding, Hilbert curve scan, histogram modification, multilevel shifting, high capacity, image recovery

INTRODUCTION

Data hiding (Chen *et al*., 2010; Luo *et al*., 2010; Lv and Lu, 2011; Zhang *et al*., 2010; Wu *et al*., 2011) is an useful technique in multimedia security (Zhao *et al*., 2010). In recent years, the technique of reversible data hiding (Hong *et al*., 2009) has drawn much attention among researchers. Compared with traditional embedding techniques, its key advantage lies in the reversibility, that is not only the hidden secret data, but also the cover image can be accurately recovered from the stego-images in decoder (Li *et al*., 2011). Accordingly, this technique is suitable for some specific applications where any distortions on cover images (e.g., military maps, diagnostic medical images, art pictures, etc.) are unacceptable after hidden data extracted.

Currently, a lot of reversible data hiding schemes have been developed; most of them can be performed in three categories: the transform domain, the compressed domain and the spatial domain. Most existing methods belong to two classic prototypes of the spatial domain, i.e., difference expansion (Tian, 2003) and histogram shifting (Ni *et al*., 2008; Hong *et al*., 2010). The principle of difference expansion (Tian, 2003) is to expand the differences of a pair of pixels to embed secret bits. In contrast, the histogram shifting method employs the zero and peak points of an image histogram to hide message and achieved reversibility.

Kim *et al*. (2009) proposed a reversible data hiding method that modifies the difference histogram between sub-sampled images. This method exploited high information redundancy among pixels in a small block to achieve high capacity. The center one of each block is fixed as the reference pixel. The data embedding processing is based on multilevel histogram shifting. In decoder, the data extraction and image recovery is an inverse processing of data embedding, the cover image pixels are recovered one after another and the secret data is extracted.

Li *et al*. (2010) proposed a reversible data hiding method named Adjacent Pixel Difference (APD) based on the neighbor pixels differences modification to increase the embedding capacity. In this method, the scan order of the image pixels adopted the inverse "S" order; this is the most commonly used the order of image pixel scan.

Luo *et al*. (2011) proposed a reversible data hiding scheme based on the sub-sampling principle. It improved Kim's method by using the median pixel of each block as the reference pixel. The data embedding processing is based on a multi-level histogram shifting mechanism with the reference of integer median in each block. In data extraction, the cover image can be accurately recovered with inverse multi-level histogram shifting mechanism strategy and the hidden data can be extracted.

This study proposes a reversible data hiding scheme based on multilevel histogram shifting. It used the order

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of Hilbert curve scan instead of traditional the order of image pixel scan to the problem of reversible data hiding in natural images. A histogram was constructed based on difference sequences of the order of Hilbert curve scan and a multilevel histogram modification mechanism was employed to hide secret data. In decoder, the host image pixels are recovered one after another. Meanwhile, the secret data was extracted from the marked adjacent pixels' differences. The purpose of this scheme lied in improving the quality of stego-images and at the same time, enhancing the embedding capacity to some extent.

PROPOSED SCHEME

Generally, the fewer seed pixels used, the more predicted errors provided. The more errors are equal or to zero, the sharper error histogram is achieved. That is to say, the more secret data are embedded.

In Kim *et al*. (2009) and Luo *et al*. (2011) method, reference block is determined as seed pixels. Moreover, seed pixels cannot be modified, these unmodified pixels will not join the embedding procedure and the capacity is decreased. On the other hand, the number of predicted errors depends on the block size, a larger block size achieves more error, vice versa. However, their method may cause undesirable distortion if the larger Partitioned blocks size is selected, the reason is the larger blocks may lead to a less sharp histogram.

In Li's method (APD), only one pixel (the left-and-top-most pixel) is adopted as seed, the least number of seed is provided; the most predicted errors are achieved. However, APD only select two pairs of peak bins and zeros bins employed histogram shifting, therefore, the capacity is not perfect.

In this study, a novel multilevel histogram shifting strategy which adopts Hilbert curve scan can make a good tradeoff between high payload and good visual quality.

Hilbert curve scan: Raster scan has been for a long time the dominant scan order in image processing for its great simplicity and extended use. Generally, the existing multilevel reversible data hiding algorithms all use raster scan. But it is not the most desirable to depict information redundancy of neighbor pixels. Therefore, in this study, we will present an alternative scan approach that is in some sense a variant of the fractal curve. Hilbert curve is a continuous fractal space-filling curve. Currently, Hilbert curve scans applied to histogram shifting are receiving much attention. Figure 1 shows Hilbert curve scan in image block sized 2×2, 4×4 and 8×8, where the blue line marks the scan direction. The small dots represent the starting point and the end point.

An edge is a boundary at which a significant change occurs in some of the physical aspects of the image. These changes manifest themselves in a variety of ways such as changes in intensity, color or texture. Figure 2 shows advantage of Hilbert curve scan in 16×16 image block compared with traditional raster scan. Figure 2a presents a target in the block which is an 8×8 block. The remains belong to background pixels. Figure 2b describes walking trace of Hilbert curve scan, Fig. 2c describes walking trace of inverse "S" scan .the target boundary is marked red links, on which the small circular dots represent the crossing of scan. It is also noticed that scanning trace is also periodically transition on boundary.

The transitions are organized in circles such that after the scanning in Fig. 2b and c, six and sixteen transitions are resulted, respectively. This means the Hilbert curve scan is capable of generating more differences equal or close to zero for data embedding.

Proposed model: The flowchart of our proposed reversible data hiding scheme is illustrated in Fig. 3, the data embedding process is shown in the dotted box on left-hand side of Fig. 3, the secret data which is a binary sequence, is hidden in the difference image by using histogram shifting algorithm to generate marked image. Later, secret data is extracted and cover image is recovered, the process of data extracting and image recovering is shown in the dotted box on right-hand side of Fig. 3.

Data embedding: Our method utilizes multilevel histogram shifting strategy in the data embedding procedure. Given an 8-bit gray scale image with sized M×N and is denoted as I. The p (x, y) is a pixel value in image I, the watermark is denoted as W. The following are the detailed data embedding steps of the proposed scheme:

Step 1: Hilbert curve scans the cover image I to generate a pixel sequence p_1, p_2… $p_{M\times N}$

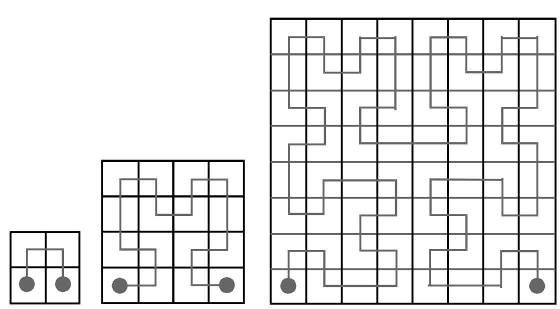

Fig. 1: Hilbert curve scan in image block sized 2×2, 4×4 and 8×8 (from left to right)

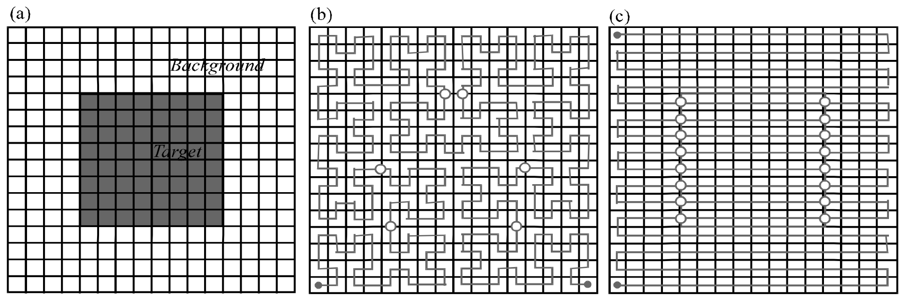

Fig. 2: Advantage of Hilbert curve scan in 16×16 image block, (a) a target in the block, (b) the crossing of Hilbert curve scan on the target boundary, (c) the crossing of inverse "S" scan on the target boundary

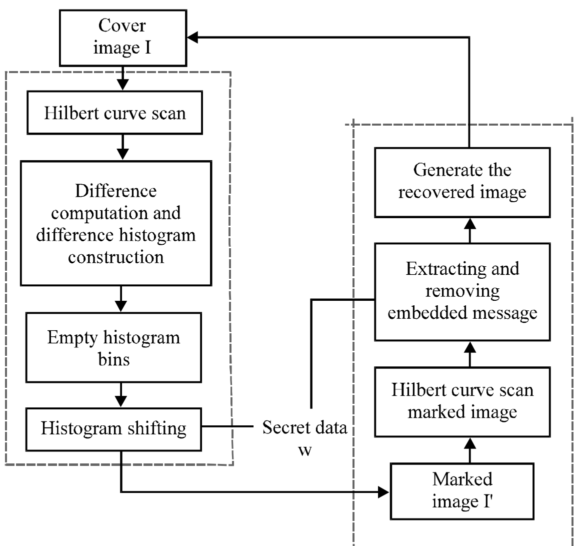

Fig. 3: Block diagram of the proposed scheme

Step 2: Compute the differences e_i between neighboring pixels according to Eq. 1 and then generate the histogram of e_i:

$$e_i = p_{i-1} - p_i \tag{1}$$

where, $2 \le i \le M \times N$, which p_1 is not changed

Step 3: Embedding level is denoted as l (l≥0). Compute the shifted differences e'_i ($2 \le i \le M \times N$,) according to Eq. 2:

$$e'_i = \begin{cases} e_i + l + 1 & \text{if } e_i > l, 2 \le i \le M \times N \\ e_i - l & \text{if } e_i < -l, 2 \le i \le M \times N \\ e_i & \text{otherwise} \end{cases} \tag{2}$$

Step 4: Started with scan e'_i, watermark W are embedded as far as $e'_i = 0$ in the range of [-l, l] and l is decreased by 1 one by one. Compute marked difference e''_i according to Eq. 3:

$$e''_i = \begin{cases} 2l + w & \text{if } e'_i = l \\ -2L + 1 - w & \text{if } e'_i = -l \\ e'_i & \text{otherwise} \end{cases} \tag{3}$$

where, $2 \le i \le M \times N$

Step 5: Generate the marked pixels sequence p' as:

$$p'_i = p_i - e'' \tag{4}$$

where, $2 \le i \le M \times N$, $p_1' = p_1$

Step 6: The marked image I' is obtained

Data extraction and Image recovery procedure: In this process, we can extract the embedded secret data and recover the cover image with distortion. The details of data extraction and image recovery are described as follows:

Step 1: Hilbert curve scans the marked image I' to generate a pixel sequence p'_i ($1 \le i \le M \times N$)

Step 2: Obtain the parameter l from the encoder. Recover the pixel sequence of the cover image by computing:

$$p_i = \begin{cases} p_1^i & \text{if } i = 1 \\ p'_i & \text{if } p_{i-1} - p'_i = 0 \text{ or } p_{i-1} - p'_i = -1, \quad 2 \le i \le M \times N \\ p'_i + l + 1 & \text{if } p_{i-1} - p'_i \ge 2l + 1, \quad 2 \le i \le M \times N \\ p_{i-1} - l & \text{if } p_{i-1} - p'_i \le -2l, \quad 2 \le i \le M \times N \\ p'_i - 1 & \text{if } -2l < p_{i-1} - p'_i < -1 \\ p'_i + l & \text{if } l < p_{i-1} - p'_i < 2l + 1 \\ p'_i + 1 & \text{if } 0 < p_{i-1} - p'_i \le l \end{cases} \tag{5}$$

Step 3: The secret data extraction is associated with *l*+1 round. *l* is decreased by 1 and the round is increased by 1 during extraction. The extracted data is recovered as:

$$w = \begin{cases} 0 & \text{if } \; p_{i-1} - p' = 2l, 2 \le i \le M \times N \\ 0 & \text{if } \; p_{i-1} - p' = -2l + 1, 2 \le i \le M \times N \\ 0 & \text{if } \; p_{i-1} - p' = 0, 2 \le i \le M \times N \\ 1 & \text{if } \; p_{i-1} - p' = -2l, 2 \le i \le M \times N \\ 1 & \text{if } \; p_{i-1} - p' = 2l + 1, 2 \le i \le M \times N \\ 1 & \text{if } \; p_{i-1} - p' = 1, 2 \le i \le M \times N \end{cases} \tag{6}$$

Step 4: Rearrange and concatenate the extracted data as

$$w = [w_1, w_2, \ldots, w_{l+1}] \tag{7}$$

Hence, the original secret bits are obtained.

Step 5: Rearrange the recovered pixel sequence p_i ($1 \le I \le M \times N$) into the cover image I

EXPERIMENTAL RESULTS AND COMPARISONS

Here, six 512×512 gray scale images are used to test the performance of our scheme. These test images are shown in Fig. 4. The embedded secret data is generated by pseudo-random number generator. The peak signal-to-noise rate (PSNR) is employed to measure the image quality. The PSNR is defined as:

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{8}$$

where, MSE is the mean square error between the cover image and stego image. MSE is defined as:

$$MSE = \frac{1}{m \times n}\sum_{x=1}^{m}\sum_{y=1}^{n}\left(b(x,y) - b'(x,y)\right)^2 \tag{9}$$

where, b (x, y) and b' (x, y) indicate the pixel values of the cover image and stego image. Generally, a higher PSNR value means better stego image quality.

In this study, our method is compared with Kim *et al.* (2009) method, APD method and Luo *et al.* (2011) method. Because the block size select the 4×4 block partition to achieve a better tradeoff between a high capacity and good marked images quality, hence, the results of Kim's and Luo's scheme are obtained with a moderate block size 4×4. The embedding level of our method and Kim's method is 9, Since APD select two pairs of peak bins and zeros bins, its embedding level is 1.

Figure 5a describes the comparison of capacity and PSNR on Lena image. Figure 5b illustrates the relation of the embedding level and capacity. It is clear that our method achieves higher embedding capacity than the other two methods under the same image quality or the embedding level for the test image on Lena.

Table 1 lists hiding capacities versus and PSNR on hiding level l = 9 for six test images. To sum up, the experimental results show that the capacities and PSNRs of the proposed method are better than Kim *et al.* (2009) method, Luo *et al.* (2011) method.

Given an l, supposed the results of these methods are obtained with block size 4×4. Figure 6-7 show that show visual impacts of the marked images obtained by different methods with l = 9. The visual quality of our method are higher than other methods.

Furthermore, our method is compared with the APD method. The comparison results are listed in Table 2 and

Fig. 4: Test images, lena, goldhill, truck, airplane, aerial, barbara

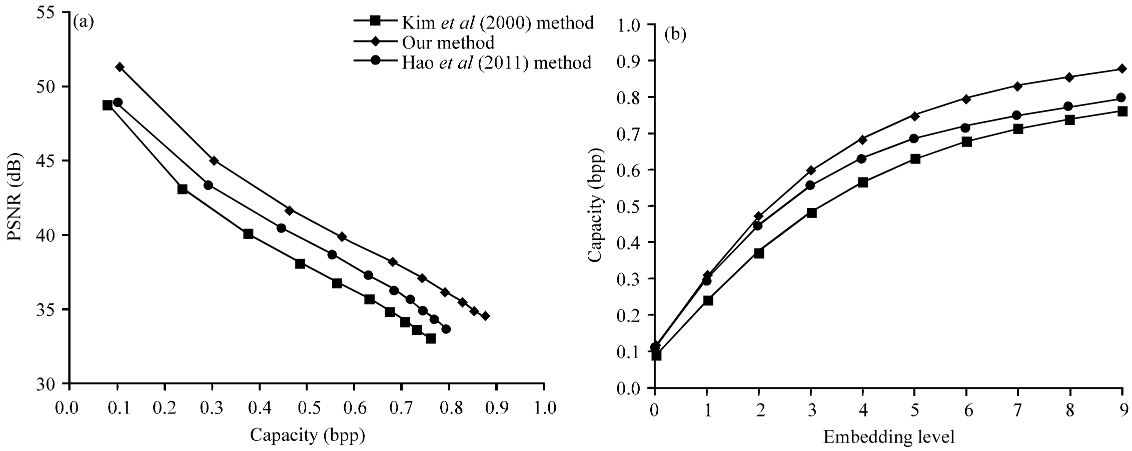

Fig. 5: Comparison of Kim *et al.* (2009), Luo *et al.* (2011) methods and our method on Lena image

Fig. 6(a-d): Visual quality comparison for with l = 9, (a)the cover image (b) marked Lena images obtained by Kim's method (198838 bits hidden, 33.06dB), (c) marked Lena images obtained by Luo's method (207010 bits hidden, 33.76dB), (d) marked Lena images obtained by our method (228736 bits hidden, 34.41dB)

Fig. 8. Because there are at most two pairs of peak-zero points are employed by Li *et al.* (2010) method, we employ APD1 and APD2 denote one and two pairs of peak-zero bins are used, respectively. Figure 8a shows that the

Table 1: Comparison of PSNR and capacity for test images with l = 9

Image	Kim *et al.* (2009) method		Luo *et al.* (2011) method		Our method	
	Capacity	PSNR	Capacity	PSNR	Capacity	PSNR
Lena	198838	33.0591	207010	33.7637	228736	34.4131
Gold hill	162518	31.3515	181810	32.3731	199146	32.4400
Car	171244	31.3985	137316	30.6023	212779	32.6802
Airplane	196634	33.3133	224697	34.3719	224960	34.5423
Aerial	108956	29.9923	120801	30.0511	134190	30.5423
Barbara	156648	31.4480	170783	31.8244	182429	32.2640

Table 2: Comparison of PSNR and capacity for APD method and our method

Method	Lena		Goldhill		Car		Airplane		Aerial		Barbara	
	Cap	PSNR	Cap	PSNR	Cap	PSNR	Cap	PSNR	Cap	PSNR	Cap	PSNR
APD_1	24976	51.14	16845	51.14	9247	51.13	18233	51.15	39621	51.14	30381	51.14
APD_2	48383	48.55	33113	48.41	18110	48.28	35868	48.44	70741	48.76	52311	48.72
Our												
$l = 0$	28284	51.13	17823	51.14	28781	51.14	40796	51.14	8961	51.14	19656	51.14
$l = 1$	79696	44.93	51672	44.64	42215	44.65	102140	45.22	26649	44.39	56940	44.69
$l = 2$	122370	41.55	82033	40.96	82971	40.91	141543	42.01	43634	40.48	89225	41.06
$l = 3$	155287	39.45	108614	38.57	103839	38.52	169344	39.98	59305	37.86	115311	38.71
$l = 4$	179192	38.02	130825	36.87	131859	36.82	187719	38.55	74113	35.93	135168	37.02
$l = 5$	196086	36.96	149223	35.57	152615	35.55	200041	37.45	88029	34.42	150016	35.70
$l = 6$	208155	36.13	165118	34.54	170819	34.57	208809	36.57	101062	33.19	161314	34.63
$l = 7$	216968	35.46	178488	33.71	187727	33.80	215680	35.83	113014	32.17	169905	33.73
$l = 8$	223495	34.90	189712	33.02	200656	33.18	220886	35.19	123943	31.30	176802	32.95
$l = 9$	228736	34.41	199146	32.44	212779	32.68	224960	34.63	134190	30.54	182429	32.26

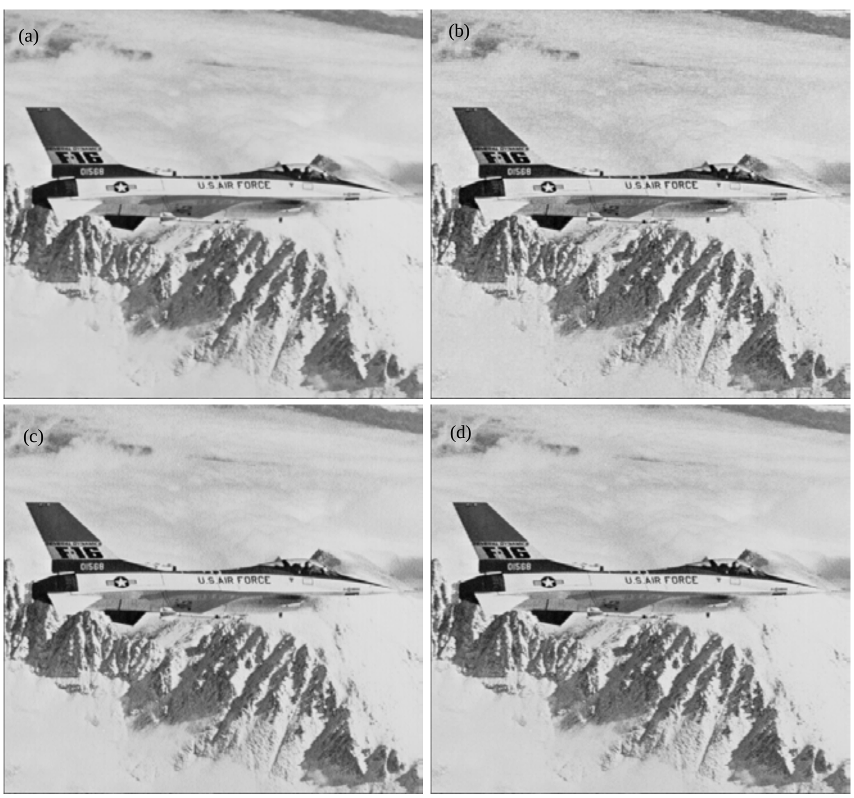

Fig. 7(a-d): Visual quality comparison for with l = 9, (a)the cover image (b) marked Airplane image obtained by Kim's method (196634 bits hidden, 33.31dB), (c) marked Airplane images obtained by Luo's method (221413 bits hidden, 33.85dB), (d) marked Airplane images obtained by our method (224960 bits hidden, 34.63dB)

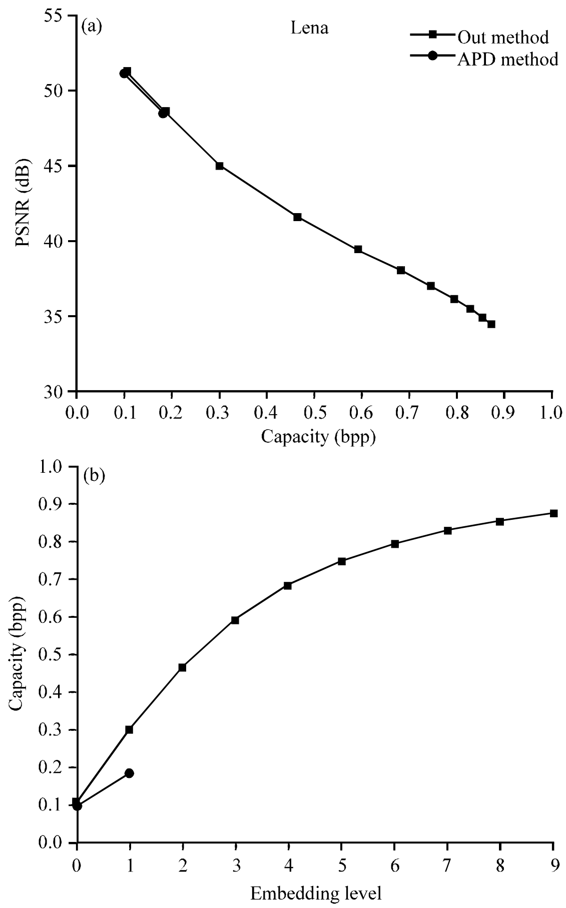

Fig. 8: Comparison of APD methods and our method on Lena image

Capacity-PSNR curves on Lena are obtained by each hiding level from round 1 to 10, while Li *et al.* (2010) curves are obtained by one and two pairs of peak-zero bins histogram shifting. As can be seen in Table 2 and Fig. 8b, it is easy to find that our method can provide a higher capacity than Li *et al.* (2010) method.

CONCLUSIONS

In this study, the Hilbert fractal curve is extended in reversible data hiding. The multi-level histogram shifting mechanism is employed to obtain large capacity. By using Hilbert curve scan approach, we not only can hide a large number of embedding but also achieve low distortion. Experimental results show that our proposed method is superior to several methods of the same kind in terms of the capacity and the PSNR. Therefore, we can conclude that our proposed method is efficient.

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