

# A reversible data hiding based on adaptive prediction technique and histogram shifting

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**Abstract**—Reversible data hiding recovers the original image from the stego-image without distortion after data extraction. In this paper, we propose a novel reversible data hiding method based on adaptive prediction techniques and histogram shifting. Because most natural images always contain edges, it is not suitable to predict these pixels using existing prediction methods. For more precise prediction, two prediction methods are adaptively used to calculate prediction error according to the characteristic of a pixel. As a result, two prediction error histograms are built. One is for pixels located at edges, and the other is for the rest pixels. Data are embedded in the image by using histogram shifting method. In addition, a new sorting method is applied to histogram shifting, which considers the differences of all pixel pairs in the neighborhood and better reflects the correlation among pixels. Through the sorting method, the prediction errors with small absolute values are arranged in the front and more embeddable pixels are preferentially processed. Therefore, the number of shifting pixels is decreased if the peaks in the histograms are all dealt with or the capacity is satisfied, which is beneficial to distortion reduction. Experimental results demonstrate that the proposed method acquires greater capacity and higher quality compared with other state-of-the-art schemes.

**Keywords:** reversible data hiding, adaptive prediction technique, histogram shifting, sorting method

## I. INTRODUCTION

Reversible data hiding, also called reversible watermarking or lossless data embedding, can accurately recover the original digital contents after data extraction. So reversible data hiding is very useful, especially for some sensitive images, such as military images, medical images and remote sensing images.

Nowadays reversible data hiding is mainly based on difference expansion (DE), prediction error expansion (PEE) and histogram shifting (HS). In 2003, Tian first proposed a reversible data hiding based on difference expansion [1]. The cover image is divided into a series of pixel pairs, and data are embedded into the differences of pixel pairs which meet the requirements of embedding. Later Alattar [2] extended the DE method from two adjacent pixels to  $K$  adjacent pixels and improved the embedding capacity. Then, there emerge many improved DE methods, such as [3, 4, 5]. In 2006, Ni et al. [8] developed the histogram-shifting method. This method first finds the peak and zero points in the histogram of images. Then the data are embedded into the pixels equal to the peak

point. The pixel values between the peak and zero points are shifted one bin to the zero point. In this algorithm, the pixels of the image are modified one at most when data embedding. And it is beneficial to improve visual quality of the stego image. But the embedding capacity was lower. For solving the problem, some algorithms [6, 7, 8, 9, 11] are proposed which integrate the DE or PE method with the histogram shifting technique. Thodi et al. [6] first proposed prediction error (PE) expansion and incorporated the histogram shifting technique into DE or PE method to efficiently reduce the size of additional information. Thereafter, many new prediction approaches are proposed. The median edge detection (MED) predictor and the gradient-adjusted prediction (GAP) are used respectively in this field. In [7], Sachnev et al. proposed a prediction method using the four pixels above, below, to the left, and to the right of a pixel, namely 4-neighborhood of a pixel, to predict its prediction value. The prediction method is combined with sorting and two-pass-testing. And the algorithm obtains higher embedding capacity and lower distortion than most of other reversible data hiding methods. These methods efficiently improve the embedding capacity and obtain high quality stego image.

In this paper, a novel reversible data hiding is proposed based on dual prediction methods and histogram shifting. The prediction method using the average of 4-neighborhood pixels of a pixel is more accurate than other prediction methods, such as MED and GAP. But in the edges of an image, the existing prediction methods are not suitable. So a new prediction method is proposed, which predicts a pixel using the average of its 4-neighborhood in smooth regions and calculates the prediction value of a pixel located in the edges by the proposed technique. For estimating whether a pixel belongs to the edges or not, a threshold is needed. Thereafter, two histograms of prediction errors are constructed. Data are embedded into the peak points according to the traditional histogram shifting method. Besides, a new sorting method is used in histogram shifting, by which more embeddable pixels are first processed. And it is advantageous to improve the performance. The experimental results show that the proposed algorithm can acquire better image quality under the same payload compared with other reversible data hiding algorithms.

The remainder of this paper is organized as follows. Section II presents the proposed scheme. In Section III, the

embedding process is depicted. Section IV shows the extraction and recovery procedure. The experimental results

## II. PROPOSED SCHEME

### A. Construct Two Histograms of The Prediction Errors

Suppose that the host image  $I$  is an  $M \times N$  gray level image and all pixels are divided into two sets: the black set and the white set (as Fig.1). The processing methods of the two sets are similar. So only is the processing method of the black set described.

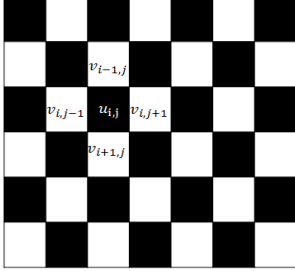


Fig.1 the black set and the white set

In general, the correlation is strong between a pixel and its neighborhood for natural images. So the prediction method based on (1) [7] is quite exact and obtains good results. However, in the edge of the image the prediction method may employ the dissimilar pixels to predict the pixel  $u_{i,j}$  in this method. As a result, the prediction value is far away from the pixel  $u_{i,j}$ . So, to more accurately predict these pixels located at the edges, we put forward a new prediction approach.

$$u'_{i,j} = \left\lfloor \frac{v_{i-1,j} + v_{i,j+1} + v_{i+1,j} + v_{i,j-1}}{4} \right\rfloor \quad (1)$$

First, the maximum and minimum in  $\{v_{i,j+1}, v_{i+1,j}, v_{i,j-1}, v_{i-1,j}\}$  are denoted as  $V_{max}$  and  $V_{min}$ . And the difference between  $V_{max}$  and  $V_{min}$ ,  $E$ , is calculated. According to the relationship between  $E$  and the threshold  $T$ , the pixel is predicted. If the difference is not larger than the threshold  $T$ , the pixel value of  $u_{i,j}$  is similar to pixel values in its neighborhood. And it is predicted by using all pixels of its neighborhood. Otherwise, the pixel  $u_{i,j}$  is regarded as the edge pixel. And its prediction value is computed according to the edge direction. Our proposed prediction methods are as follow.

$$u'_{i,j} = \begin{cases} \left\lfloor \frac{v_{i-1,j} + v_{i,j+1} + v_{i+1,j} + v_{i,j-1}}{4} \right\rfloor & \text{if } E \geq T \\ \left\lfloor \frac{v_{i-1,j} + v_{i+1,j}}{2} \right\rfloor & \text{if } e_h \geq e_v \text{ and } E < T \\ \left\lfloor \frac{v_{i,j-1} + v_{i,j+1}}{2} \right\rfloor & \text{if } e_h < e_v \text{ and } E < T \end{cases} \quad (2)$$

where  $e_h = |v_{i,j-1} - v_{i,j+1}|$ ,  $e_v = |v_{i-1,j} - v_{i+1,j}|$ . If  $e_h \geq e_v$ , the pixel  $u_{i,j}$  is supposed to be similar to its adjacent pixels located in vertical direction and is predicted using its vertical neighborhood. Otherwise, it should be predicted using

adjacent pixels located in horizontal direction. As shown in

71	95	110
65	96	99
66	95	97

(a)

$u' = 88$  if using (1)  
 $u' = 95$  if using the new prediction method

97	85	88
98	95	93
129	135	110

(b)

$u' = 102$  if using (1)  
 $u' = 95$  if using the new prediction method

Fig.2 the pixels that are more suitable to be predicted using (2)

Fig.2, we can find the new prediction method obtains more accurate pixel values than the average method.

Next, the prediction errors are calculated by the following equation.

$$d_{i,j} = u_{i,j} - u'_{i,j} \quad (3)$$

Thereafter, two histograms  $H_1$  and  $H_2$  can be constructed.  $H_1$  is composed of prediction errors of pixels located at the edge, while  $H_2$  corresponds to the prediction errors of the rest pixels. Then, two peak points are selected to create the free space for hiding to-be-embedded information in each histogram.

### B. The Selection of The Threshold $T$

In histogram shifting, the available capacity is the number of pixels in peak point bins. Because the threshold  $T$  affects the construction of histograms, the selection of  $T$  is relative to the embeddable capacity. The optimal  $T$  corresponds to the maximum capacity. Reflecting in the two histograms, the sum of elements in peak point bins must be the maximum.  $T$  is determined based on the enumeration method. Suppose the capacity is  $C$  when  $T$  equals 0. Fig.3 demonstrates the increments compared with  $C$  under different  $T$ s for six standard images: plane, lena, baboon, lake, boat, barbara. The conclusion is obtained that the threshold  $T$  really has an effect on the capacity. And it is obvious that the embedding capacity can be improved through selecting the optimal threshold  $T$ .

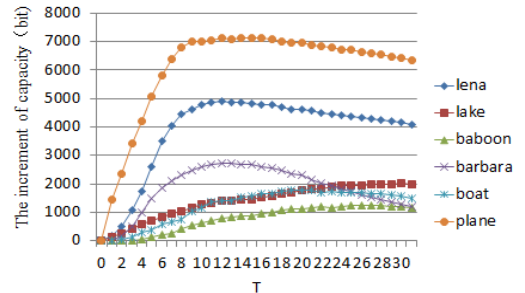


Fig.3 the increment of capacity vs. the threshold  $T$

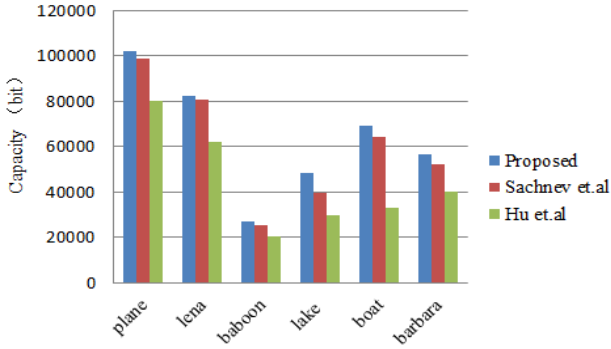


Fig.4 Capacity comparison of our method and other methods

In addition, Fig.4 shows the capacities of our method with optimal  $T$  and the capacities of other methods. It clearly illustrates that the proposed prediction method is superior to others. And as a result, when the optimal  $T$  is determined, the edges are suitably selected, which is contributive for more accurately predicting pixel values and improving the capacity.

### C. Data Embedding and Extraction Based on Sorting

In this paper, the histogram shifting method based on sorting is proposed to embed the secret data. Data embedding and extraction process of the black set and the white set is similar. So we use the black set as an example to elaborate the process.

When using histogram shifting method to embed data, the two peak points of the histogram should be found first. Here, suppose that the two peak points of the histogram of prediction errors are  $P^+$  and  $P^-$ . Without loss of generality, we assume  $P^+ > P^-$ . Then the prediction errors  $d_{i,j}$  can be modified to hide information as follows:

$$D_{i,j} = \begin{cases} d_{i,j} + w, & \text{if } d_{i,j} = P^+ \\ d_{i,j} - w, & \text{if } d_{i,j} = P^- \\ d_{i,j} + 1, & \text{if } d_{i,j} > P^+ \\ d_{i,j} - 1, & \text{if } d_{i,j} < P^- \end{cases} \quad (4)$$

where  $w$  is the to-be-embedded data,  $w \in (0,1)$ .

Then the marked pixel value is changed to  $U_{i,j}$  as

$$U_{i,j} = u'_{i,j} + D_{i,j} \quad (5)$$

We first use the histogram  $H_2$  to embed data according to (4). When the peak points of the histogram  $H_2$  can't accommodate the embedding data, the histogram  $H_1$  is exploited. Its two peak points should also be found first. Then embed data using (4), that is, embed data into errors equal to the two peak points and shift the rest errors. Finally, employ (5) to obtain the stego image.

In the data embedding process, a sorting technique is proposed, which is beneficial to hide data with lower distortion. The purpose of sorting is to arrange more embeddable pixels in the front and make them be processed preferentially. As a result, the number of shifting pixels is

reduced with the same capacity and the distortion is lower than that without using sorting method.

Since the two histograms are obtained by using two difference prediction methods, two sorting techniques are designed. We assume the sorting parameter is  $\delta_{i,j}$ . For the prediction errors corresponding to the histogram  $H_2$ , their processing order is determined by local variances as the following equation presents.

$$\delta_{i,j} = \frac{1}{6} \sum_{k=1}^6 (\partial_k - \bar{\partial})^2 \quad (6)$$

where  $\partial_1 = |v_{i-1,j} - v_{i+1,j}|$ ,  $\partial_2 = |v_{i-1,j} - v_{i,j-1}|$ ,  $\partial_3 = |v_{i-1,j} - v_{i,j+1}|$ ,  $\partial_4 = |v_{i+1,j} - v_{i,j-1}|$ ,  $\partial_5 = |v_{i+1,j} - v_{i,j+1}|$ ,  $\partial_6 = |v_{i,j-1} - v_{i,j+1}|$ ,  $\bar{\partial} = (\sum_{k=1}^6 \partial_k) / 6$ . Equation (6) adequately considers the correlations of all pixel pairs in the neighborhood.

For the prediction errors in the histogram  $H_1$ , their processing order is determined by the following equation.

$$\delta_{i,j} = \begin{cases} |d_v| & \text{if } |d_v| < |d_h| \\ |d_h| & \text{otherwise} \end{cases} \quad (7)$$

where  $d_v = v_{i-1,j} - v_{i+1,j}$ ,  $d_h = v_{i,j-1} - v_{i,j+1}$ .

Through (6) and (7), the values of  $\delta_{i,j}$  are calculated and sorted in ascending order. Consequently, the pixels with small  $\delta_{i,j}$  are prior to be processed.

Next, an example is used to illustrate the benefit of sorting (see Fig.5).

The prediction errors of the pixels marked in yellow are computed by (1) and (3). Then the histogram of errors is constructed. For briefly explaining the process, one peak points is used to embed data. From Fig.6, the peak point is  $-1$ . Suppose the embedding data is [110010]. The errors equal to the peak point are used to embed data and errors less than the peak point is shifted to the left. If sorting technique is not used, five pixels should be shifted when the data are all embedded. However, only is one pixel shifted if the sorting method is employed. And the result completely illustrates that sorting is efficient to improve the performance by reducing distortion.

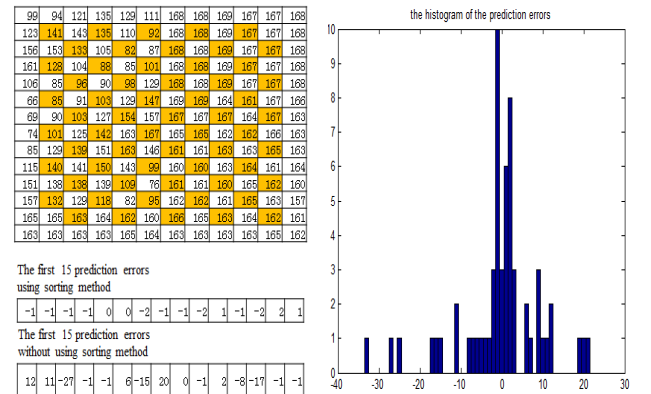


Fig.5 An example illustrating the benefit of sorting

During extraction, if the prediction error  $D_{i,j}$  belongs to the set  $(P^+, P^-, P^+ + 1, P^- - 1)$ , the data  $w$  can be extracted according to (8):

$$w = \begin{cases} 0 & \text{if } D_{i,j} = P^+ \text{ or } D_{i,j} = P^- \\ 1 & \text{if } D_{i,j} = P^+ + 1 \text{ or } D_{i,j} = P^- - 1 \end{cases} \quad (8)$$

Subsequently, shifting is used to recover the original image. The original prediction error is computed as:

$$d_{i,j} = \begin{cases} D_{i,j} & \text{if } P^- \leq D_{i,j} \leq P^+ \\ D_{i,j} - 1 & \text{if } D_{i,j} \geq P^+ + 1 \\ D_{i,j} + 1 & \text{if } D_{i,j} \leq P^- - 1 \end{cases} \quad (9)$$

Finally, the recover pixel value is calculated by  $u_{i,j} = u'_{i,j} + d_{i,j}$ .

#### D. Overflow and Underflow Problem

During data embedding, the pixels are modified through embedding and shifting operations. And the proposed scheme basically modifies each pixel value at most by one. So the overflow or underflow problem may be caused for pixels whose value equals 0 or 255. In order to avoid this problem, boundary pixels 0 and 255 should be changed to 1 or 254 before data embedding. And for recognizing these pixels in extraction process, their location map should be recorded by a location map  $L$ , which is compressed by arithmetic coding. The compressed location map is embedded into the embeddable pixels with the to-be-embedded data and its length is regarded as a part of the extra information.

### III. THE EMBEDDING PROCEDURE

In order to extract data and recover the original image, the extra information should be recorded, including the peak points (16bits) of the two histograms, the threshold  $T$  (5bits), the length of the payload data (17bits) and the length of the location map (7bits). The extra information will be embedded into the least significant bits (LSBs) of the first 45 pixels in the first row. And the original LSBs are recorded and embedded into the peak points with the payload data. The embedding procedure of the black set is similar to the white set. So we only describe the black set embedding procedure.

Step 1: Construct the two histograms. Threshold  $T$  is first selected to obtain the maximum capacity. According to  $T$ , calculate the prediction values using (2). And obtain the prediction errors by (3). Then construct the two histograms  $H_1$  and  $H_2$ . At the same time, the elements of the two histograms are respectively sorted using (6) and (7), i.e. the errors belonging to  $H_2$  are sorted by (6) and the rest by (7). Next, find the two peak points  $P^+$  and  $P^-$  of  $H_2$ . If the number of the elements equal to the two peak points is less than the length of the payload data, the two peak points  $H_1$  should also be used to embed data.

Step 2: Embed data. The original LSBs of the first 45 pixels in the first row along with the payload data are embedded into the prediction errors as discussed in Section II. Meanwhile,

the extra information is embedded into the LSBs of the first 45 pixels in the first row.

Step 3: Obtain the stego image. After data embedding, the modified prediction errors  $D_{i,j}$  can be achieved. Then the marked pixels can be calculated using (5).

After Step 3, the embedding process of the black set is finished. The white set is processed similar to the black set. When the two sets are all processed, the stego image is obtained.

### IV. THE EXTRACTION AND RECOVERY PROCEDURE

In fact, the extraction and recovery procedure is the inverse of the double embedding schemes. Using the black set as an example, the extraction and recovery process is as follows.

Step 1: Extract the LSBs of the first 45 pixels in the first row. The extra information, including the peak points, the size of the location map, the threshold  $T$  and the length of the payload data  $|w|$ , is obtained.

Step 2: According to the threshold  $T$ , calculate the prediction errors and sort the prediction errors as described in Section II.

Step 3: Extract the secret data and recover the original prediction errors. Scanning the prediction errors, if the prediction error equals  $P^+$  or  $P^-$ , the message 0 is extracted. And the message 1 is extracted if the prediction error equals  $P^+ + 1$  or  $P^- - 1$ . When the length of the extracted data equals  $|w|$ , the procedure is stopped. The original prediction errors are computed using (9).

Step 4: Recover the original image. After obtaining the original prediction errors, the pixel values of the original image can be calculated by  $u_{i,j} = u'_{i,j} + d_{i,j}$ .

Then the white set is disposed similar to the black set. After, the extraction and recovery process is finished.

### V. EXPERIMENTAL RESULTS

In order to illustrate the superiority of our proposed scheme over other existing methods, some experimental results are presented in this part. Several standard grayscale images with size  $512 \times 512$  are selected as test images as shown in Fig.6. The evaluation criterion of stego image quality is peak signal to noise ratio (PSNR).



Fig.6 Test images: lena, plane, baboon, barbara, lake, boat

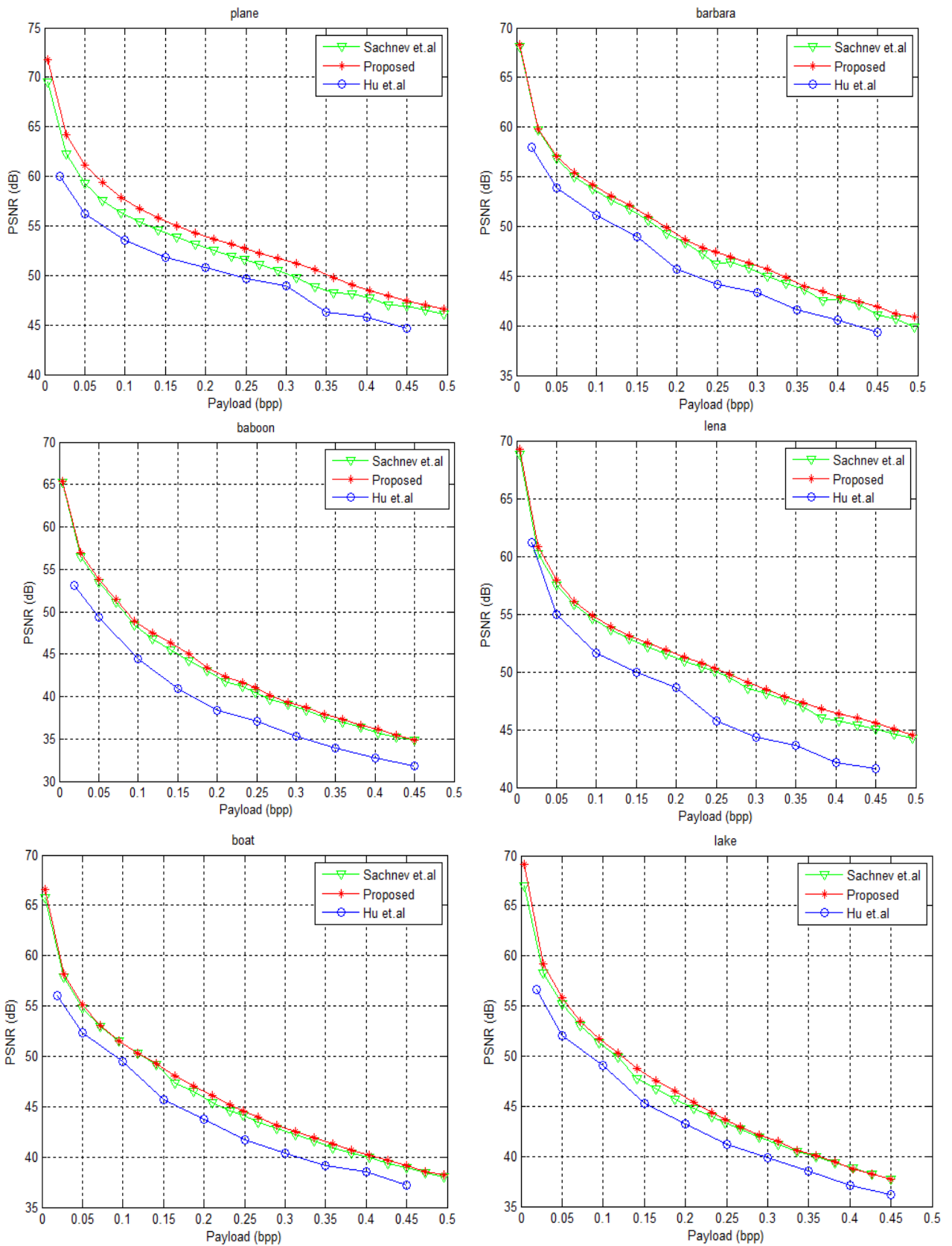


Fig.7 PSNR with respect to embedding rate for three schemes on different images

TABLE I COMPARISON OF OUR METHOD AND SACHNEV ET.AL IN [7]

Image	Proposed		Sachnev et.al	
	Capacity(bits)	PSNR(dB)	Capacity(bits)	PSNR(dB)
lena	7000	60.8096	7000	60.2253
	43000	52.4612	43000	52.1392
	61000	50.7229	61000	50.4168
plane	82000	48.4288	82000	48.0863
	7000	64.2273	7000	62.2648
	43000	55.0361	43000	53.8501
baboon	61000	53.1128	61000	51.9646
	82000	51.1887	82000	49.7385
	7000	56.9626	7000	56.5411
lake	43000	45.0641	43000	44.1767
	61000	41.6778	61000	41.1560
	82000	38.7055	82000	38.3046
boat	7000	59.2485	7000	58.3248
	43000	47.5830	43000	46.7638
	61000	44.4134	61000	43.9759
barbara	82000	41.4769	82000	41.2261
	7000	58.2169	7000	57.8449
	43000	48.0666	43000	47.3520
barbara	61000	45.1707	61000	44.5512
	82000	42.4723	82000	42.2017
	7000	59.8480	7000	59.6711
barbara	43000	50.9712	43000	50.5656
	61000	47.8058	61000	47.1892
	82000	45.6691	82000	44.9752

We present the comparative results of the proposed method and [7] in Table I. And it shows that our method is better in performance. When the embedding capacity is the same, our method achieves higher image quality. For plane, the PSNR values are 64.2273 dB and 51.1887 dB respectively in our method when the embedding capacities are 7000 bits and 82000 bits, which are larger than 62.2648 dB and 49.7385 dB in [7]. Meanwhile, more experimental results compared with [7, 9] are shown in Fig.7. For barbara containing many edges, the performance of our method is significantly superior to other two methods when the capacity increase, which reveals our proposed method is efficient for texture images. For plane, the PSNR values of our method always are larger than other methods'. From the results, it illustrates that the proposed method is effective on improving the performance.

As a matter of fact, when the capacity is low, the dominant factor affecting the performance is the sorting method. And the results show that sorting can really improve the performance. Under the high capacity, the combined effects of the sorting and prediction methods determine the experimental results. On the whole, our scheme can achieve higher image quality and greater capacity than other methods.

## VI. CONCLUSIONS

A novel reversible data hiding based on adaptive prediction method and histogram shifting is proposed. Based on adaptive prediction method, two histograms are constructed to embed data. In addition, a new sorting technique is utilized to improve the performance. The experimental results show that the proposed algorithm can achieve higher capacity and preserve good image quality. Although the prediction method achieves better performance, the prediction method isn't the best. In the future, we will further research and discuss the prediction approach.

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