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Prediction-based Reversible Data Hiding Using Empirical Histograms in Images

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Abstract

This paper presents a multilevel reversible data hiding method based on histogram shifting which can recover the original image losslessly after the hidden data has been extracted from the stego-image. The method of prediction is adopted in our proposed scheme and prediction errors are produced to explore the similarity of neighboring pixels. In this article, we propose two different predictors to generate the prediction errors, where the prediction is carried out using the center prediction method and the JPEG-LS median edge predictor (MED) to exploit the correlation among the neighboring pixels. Instead of the original image, these prediction errors are used to hide the secret information. Moreover, we also present an improved method to search for peak and zero pairs and also talk about the analogy of the same to improve the histogram shifting method for huge embedding capacity and high peak signal-to-noise ratio (PSNR). In the one-level hiding, our method keeps image qualities larger than 53 dB and the ratio of embedding capacity has 0.43 bpp (bit per pixel). Besides, the concept with multiple layer embedding procedure is applied for obtaining high capacity, and the performance is demonstrated in the experimental results. From our experimental results and analytical reasoning, it shows that the proposed scheme has higher PSNR and high data embedding capacity than that of other reversible data hiding methods presented in the literature.

Keywords: Reversible data hiding, steganography, histogram shifting

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1. Introduction

Steganography is the art and science of data hiding technique that provides various purposes such as security protection, and authentication [1][2][3]. The technique of steganography is to hide messages into meaningful images without causing noticeable signs to malicious persons, where the meaningful images are also called as cover images. The well known method in the data hiding in images is the Least Significant Bit, LSB substitution [4]. This method directly replaces the right most insignificant bit, i.e. the Least Significant Bit LSB with the confidential information, thus achieving the effect of information hiding. Wide ranges of alternatives and modifications have also been presented by researchers to Least Significant Bit [5][6][7] to improve upon it.

Spatial domain, i.e. LSB substitution[4], image hiding research is done directly on the pixel information and does not need to spend too much computing time and complexity compared to the frequency domain, i.e. DCT, DWT, and DFT [19][20]. Moreover the spatial domain data hiding is relatively simple. The main benefit of stego-images as compared to the encrypted images is that they do not reveal the fact that some secret information is hidden in them.

However, in all of the above stated data hiding methods the original image and the embedded message do not share any relationship among after being transmitted. Therefore the receiver has no concern to restore the cover image after secret data extraction. However in recent years some other type of images like medical, military images or artwork preserving have raised the need for the requirement of reversible information hiding techniques as these images are required to be restored to the initial state to facilitate the identification and preserve the original content. So, in order to accomplish the goal to recover the cover image, lossless reversible data hiding techniques have come into existence. Reversible hiding algorithms allow extraction of intact hidden secret information from the stego digital carrier image and losslessly recover the original image to its initial state as well [8][9][10][11][12][13][14][15][16] and [23][24][25].

The main aim of data hiding scheme, which contains reversible and irreversible data hiding, is to achieve a good balance point between the image quality and the embedding capacity and has been a challenging task. Some prior work has been done for reversible data hiding in the past decade. The first method was proposed by Honsinger et al. [18] in 2001 which used modulo-256 arithmetic to achieve reversibility. The embedding formula is $I_w = (I + W) \bmod 256$ in which I denotes the original image and I_w the stego-image and the watermark $W = W(H(I), k)$, where $H(I)$ denotes the hash function and k the secret key. The usage of modulus 256 addition, the over/underflow is prevented and reversibility is achieved.

Basically the reversible data hiding methods developed till date can be classified into two main types based on the embedding domain. The first type applies data embedding in the spatial domain [8][9][10][11][12][13][14][15][16], with relatively low capacity, while the other type utilizes the coefficients in the transform domains, such as the integer DCT and the integer wavelet transform domains to hide the data [19, 20]. Apart from these some other schemes based on vector quantization have also been proposed [22][23]. So far, the previous works of reversible data hiding are focused on the developed techniques based on difference expansion and histogram shifting.

In 2003, a scheme lossless watermarking algorithm based on circular interpretation of bijective transformation was proposed [12]. In this approach, the histograms of quantized pixel values are mapped to a circle. The relative orientation of the histograms of two groups of pixels hides only one bit of an embedded message. Therefore, this scheme can achieve only limited hiding capacity. Later, Tian [9] proposed a scheme for reversible data hiding called difference expansion (DE) based on the addition rather than replacement. The message was embedded in the high-pass band of the Haar wavelet decomposition. In this scheme the redundancy between the two neighboring pixels was examined and the secret data to be embedded was appended with the difference value thus expanding the new difference value by 2. In 2004, Alattar [9] proposed a reversible watermarking scheme for color images by using a generalized integer transform for the DE. Kamstra et al. [10] improved the DE scheme by using sorting to increase the efficiency of lossless compression. Thodi [11] proposed a prediction-error expansion approach that better exploited the correlation inherent in the neighborhood of a pixel than the DE scheme.

In 2006, Ni et al. [8] proposed a reversible data hiding technique based on histogram shifting. The scheme used the zero point and peak point of an image histogram to hide message and achieved reversibility. The scheme was quite simple and caused only slight distortion with low complexity. However, the experimental results demonstrate that its largest hiding capacity is only about 5000 bits when the test image is 8-bit gray scale and of size 512×512. In 2008, Lin et al. [15] proposed a reversible data hiding based on histogram modification of difference image generated from the linear prediction scheme. Besides that they also proposed to apply the algorithm multiple times in order to achieve high embedding capacity.

It does not matter whether scholars hide embedded messages in the spatial, frequency or compression domains. A common approach in reversible data hiding is to define a free space in an image first, also called the hiding area, then hide the embedded message in that area. To hide a larger payload in an image and maintain the highest possible image quality of a marked image at the same time, inspired by Ni et al.'s scheme [8], we explore the peak point of the histogram in pixel differences in an image, then slightly modify the pixel values to hide the embedded message. As we show later in this paper, our proposed scheme uses a multilevel hiding strategy to provide large hiding capacity while keeping distortion low.

In this paper we present a reversible data hiding technique inheriting the scheme proposed by Lin et al. in 2008 which uses the difference between the predicted pixel and the original pixel values to hide the secret message. To overcome the aforementioned problems of increasing the PSNR value and the embedding capacity we propose a prediction based reversible non-overlapping block histogram shifting method. In our method, the confidential information is hidden in the peak point of the prediction errors generated by two of the proposed methods. So, greater the value of the peak point, i.e. smooth region more the number of bits can be embedded. Hence smooth images have more hiding reserves. The experimental results show that PSNR values remains around 49dB which is very good quality. The performance of embedding capacity is also maintained as peak point, where each pixel value in peak point will hide at least 1 bit. Reversible image hiding in order to restore image is bound to record some additional information hence we embed the overhead information in the temporary image to reduce the transmission burden. Hence the proposed algorithm outperforms other methods both in image quality and hiding capacity.

The rest of the paper is structured as follows. In the next section some previous works related to Ni's and Lin's algorithm are briefly reviewed. Section 3 describes the framework of the proposed method of reversible data hiding. It will be divided into three subsections which will illustrate the prediction procedures and the embedding and extracting algorithms. In section 4 we analyze and demonstrate the experimental result of proposed scheme in terms of PSNR and hiding capacity and its benefit over other methods. Conclusions follow up in section 5 with some references at the end.

2. Preliminary

Two preliminary methods are introduced in this section. One is histogram-based scheme proposed by Ni et al. in 2006. The other is multi-level approach proposed by Lin et al. in 2008.

2.1 Review of Ni et al. 's Scheme

We briefly review the Ni et al. method of histogram-based for reversible data hiding [8]. This method utilizes the peak point of the image histogram to embed the secret information into the image.

Firstly, input an image and generate a histogram distribution. Then, all peak and zero points are searched in the image histogram. A peak point is a pixel values having the most number of occurrences in the image. In the contrast, a zero point is pixel value not having occurrences in the image. In the histogram shifting approach the pixel values lying between the range of peak and zero point are need to be modified while pixels outside the range are left unchanged. The capacity of embedding data depends on the maxima or the peak size. A histogram of the sample image can be seen in **Fig. 1**. Also in the above case if there is no zero point the minima point is taken as the zero point and before embedding the pixel values having the minima points need to be recorded. Accordingly this extra data is sent as the overhead information. Here we will briefly describe the algorithm:

The embedding procedure of Ni et al.'s method can be illustrated as follows:

1. Input an image of size $M \times N$ with the pixel grayscale values x, $x \in [0,255]$.
2. Generate its histogram H(x).
3. Find a peak point (a) and a minimum point (b) in the generated histogram H(x). The peak point corresponds to the pixel value which has the highest occurrence in the image and the minimum point corresponds to the gray value which has the least occurrence in the image. For instance, in case of Lena image the zero or minima point assumes h(250) and the maxima number of pixels assumes h(154) as shown in the **Fig. 1**
4. The whole image is scanned in a raster scan order, i.e. left to right and top to bottom. The scale values of the pixels between the peak (a) and minima point (b) are incremented by 1, i.e. the histogram is shifted to the right by 1 unit leaving the gray value b empty like 155 in our example.
5. The whole image is scanned once again in the same order. If the gray value of a pixel equal to the peak value (a) is encountered the secret data bit is embedded into it. If the to be embedded bit is '1', then the pixel value is incremented, i.e. 'a+1', otherwise, if it is '0' the pixel value is retained, i.e. 'a'.

However, in the scheme proposed by Ni et al., the largest embedding capacity solely depends upon the peak gray value of the image and therefore despite of high PSNR has very low embedding capacity.

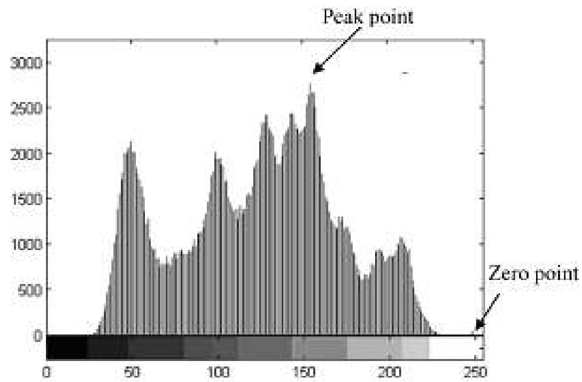


Fig. 1. Histogram of Lean Image

2.2 Lin et al.'s Multi-Level Scheme

In order to improve upon the Ni et al.'s scheme, Lin et al. [15] proposed a multilevel reversible data hiding scheme. In their scheme, the authors applied the histogram shifting and modification method of Ni et al. on the difference image generated by linear prediction and uses the peak points of difference image to hide the secret data into the cover image. The embedding capacity of this scheme also depends upon the peak value of the difference image histogram. Lin et al. also proposed to repeatedly apply the same approach to achieve high embedding capacity. The embedding procedure of Lin et al. can be illustrated as follows:

1. The original image is divided into 4×4 non overlapping blocks.
2. Difference image of size 4×3 is generated using the linear prediction scheme according to $d(i,j) = I(i,j) - I(i,j-1), 0 \le i \le 3$ and $0 \le j \le 2$, where $I(i,j)$ is the current pixel.
3. The histogram other difference is generated and the similar procedure as of Ni et al. is followed to embed secret data at the peak point of the histogram.
4. Later, the stego image is reconstructed using the reverse of the prediction algorithm.

Lin et al.'s multi-level scheme has larger embedding capacity than Ni et al.'s approach because Lin et al.'s scheme used the neighbor pixels differencing to seek larger number of peak point. Although, Lin et al.'s scheme can obtain high embedding capacity, the scheme does not fully exploited relationship between current pixel and neighbor pixel.

3. Proposed Method

In this paper, we propose to use prediction errors to apply the histogram shifting algorithm. The reasoning behind this is that the histogram shifting algorithm uses the peak point to embed the secret information into the algorithm. From gray-value distribution in an image, we observed the characteristics of an image carefully and found out that the pixel values are highly correlated among each other. Therefore, to enhance the embedding capacity of the proposed scheme, we pursue to generate more number of peak points that are the difference between predictor and its neighbor pixels. Moreover, we use the difference values whose histogram generally follows the Laplacian distribution and MED prediction. The flowchart of the working of the proposed scheme is depicted in **Fig. 2**. The detail of the prediction method followed by the embedding and extracting algorithm is given as below.

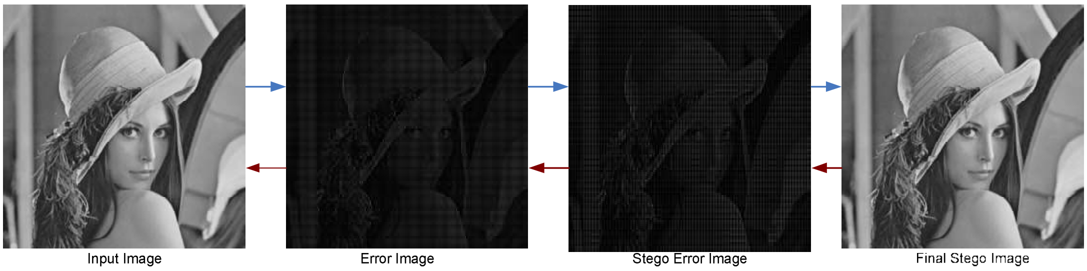


Fig. 2. Flowchart describing our embedding and extracting scheme

3.1 Generation Of Prediction Errors

The embedding process of our proposed scheme involves calculating the prediction errors to generate a difference image from the correlation of the neighborhood pixels and then embedding the secret bits in the prediction errors. Here, we can not predict the complete image at one go as in traditional prediction technique because in that case the error propagation will be very large. So, to generate the prediction errors, an image is divided into non-overlapping blocks and then uses the prediction technique to generate the prediction error blocks. In the prediction, we have to leave some pixels unused for successful reconstruction. In our proposed scheme we explored two different prediction schemes as illustrated following:

3.1.1 Prediction Using The Centre Pixel

This method of prediction is very useful when the image is to be divided into non-overlapping blocks as in our algorithm (described later in section 3.2). In this kind of prediction technique, we use the central pixel to predict the pixels since the pixels are highly correlated and similar to the central pixel. The error block is constructed by taking the difference between the predicted and the original values. The **Fig. 3** presents this concept:

A1	A2	A3
A4	**C**	A5
A6	A7	A8

Fig. 3. Linear Prediction using Central pixel

Here in the above case the pixels A1, A2, A3, A4, A5, A6, A7, A8 are predicted as *C* and the difference or error block is constructed as **Fig. 4**:

A1-C	A2-C	A3-C
A4-C	**C**	A5-C
A6-C	A7-C	A8-C

Fig. 4. Prediction Error Block for Central prediction

3.1.2 MED Prediction

The JPEG-LS prediction technique [17] can analyze the local texture among the three pixels (showing in **Fig. 5**). It is a low complexity algorithm with an inherent edge detection mechanism. The pixel x is predicted as x' in the following manner scanning the image block in the raster scan order, and the prediction rule is followed as Eq. (1).

c	b	
a	$\mathbf{x}$	

Fig. 5. MED Predictor

$$x' = \begin{cases} \min(a,b) & if \quad c \ge \max(a,b) \\ \max(a,b) & if \quad c \le \min(a,b) \\ a+b-c & otherwise \end{cases} \tag{1}$$

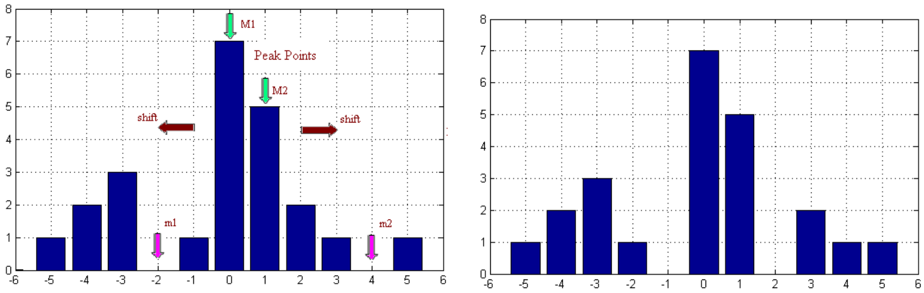
Once the predicted value x' is calculated the difference between the original pixel x and x' is determined. But however, here we can observe that the boundary pixels are left unpredicted due to the unavailability of the causal pixels which will severely affect the embedding capacity as only the prediction error pixels are used for data hiding. So, in order to increase upon the capacity we predict the pixels of the first row and first column using linear prediction from the first pixel of the block located at position (0, 0). So, the final prediction error block will look like as shown in **Fig. 6**, where X' is the predicted value using MED scheme.

$X(0,0)$	$X(0,1)$- $X(0,0)$	$X(0,2)$- $X(0,0)$
$X(1,0)$- $X(0,0)$	$X'(1,1)$- $X'(1,1)$	$X'(1,2)$- $X'(1,2)$
$X(2,0)$- $X(0,0)$	$X'(2,1)$-$X'(2,1)$	$X'(2,2)$- $X'(2,2)$

Fig. 6. Prediction Error block for MED prediction

3.2 Modified Histogram Shifting Algorithm

In this subsection, we describe our improved histogram shifting algorithm. Since, we know that the difference image histogram comes from prediction error, its histogram follows a Laplacian distribution and hence it will consist of peaks centered around zero and zero points near the extremes. So, in order to achieve high embedding capacity we first describe how to select peak points and achieve shifting.



(a) (b)

Fig. 7. An illustrate of our modified shifting scheme: (a) Finding peak and zero points; (b) After shifting

The modified shifting algorithm is shown as below.

1. Search for the two maxima or peak points, i.e. error values having the highest number of pixel values M_1 and M_2, from the histogram such that $M_1<M_2$ as shown in **Fig. 7-(a).**
2. Find the corresponding zero points (m_1, m_2) such that m_1 is just smaller to the first peak point (M_1) and m_2 is just greater than the second peak point (M_2). This is done in order to avoid overlapping in the shifting phase.
3. Shift the histogram between (m_1, M_1) left by 1 unit and the histogram between (M_2, m_2) right by 1 unit. Take care of the open intervals. The histogram shifting rule can be illustrated with the help of the following equation:

$$B'_j = \begin{cases} B_j - 1, if\ B_j \in (m_1, M_1) \\ B_j + 1, if\ B_j \in (M_2, m_2) \\ B_j, \quad otherwise \end{cases} \tag{2}$$

where, B_j in the original image pixel and B'_j is the shifted histogram value. Refer **Fig. 7(a)** for shift direction for the two peak points. Thus, we have created the required space for data embedding at the peak points as depicted in **Fig. 7-(b)** at locations -1 and 2, respectively.

3.3 Emedding Algorithm

The embedding procedure can be described as follows:

1. Let I be an 8-bit gray scale image of size $M \times N$, S be the secret message s_i, $s_i \in [0,1]$, I' be the final stego image and 't' be the hiding times.
2. Divide the original cover image into non-overlapping blocks with size $K \times K$.
3. Generate the prediction error block (B) for each cover image block using the prediction algorithm presented in section 3.1.
4. Generate the histogram of the error block leaving the causal pixels unused. For example, at position (K/2, K/2) corresponding to the central prediction mechanism and pixels corresponding to the position (0, 0) for MED prediction based scheme are not included into the generation of histogram. Note, leaving these values is very important because the prediction depends on this value to a great extent and if gets altered it would affect all the neighboring pixels and the PSNR value will go down.
5. After the histogram generation the improved histogram shifting algorithm is performed to make space for the data to be embedded B'_j is formed.
6. All the prediction error pixels of B'_j having the value the same as that of the peak points, M_1 and M_2, are modified as follows according to the to be embedded secret bit s_i:

$$B''_j = \begin{cases} B_j - s_i, if\ B'_j = M_1 \\ B_j + s_i, if\ B'_j = M_2 \\ B'_j, \quad otherwise \end{cases} \tag{3}$$

7. For the case of multi-level data hiding the steps 4-6 are repeated '*t*' times and with each iteration the value of the prediction error block is updated as: $B'_j = B''_j$.
8. Perform the inversed prediction transformation to construct the final stego or marked image with the embedded secret data.

Here, we will describe the complete procedure with the help of an example. Consider an image block of size 3×3 as shown in **Fig. 8-(a)**. We firstly chose the central pixel as a predictor to predict the other pixel of the block and calculate the prediction error block (*B*), the result is shown in **Fig. 8-(b)**. Then, generating the histogram of the difference values as shown in the **Fig. 8-(c)**, and finding the peak and zero points as: $(M_1, M_2) = (0, 1)$ and $(m_1, m_2) = (-2, 2)$. So, since the embedding equals to the number of peak points, in this example it is 7(=4+3). Hence, the random secret bits generated are listing as: 0, 0, 0, 0, 1, 0, 0.

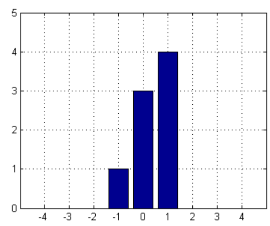
Now the histogram shifting and embedding procedure are applied. According to Eq. (2), in this case we shift histogram left by 1 unit in the range (-2, 0) and right by 1 unit in range (1, 2), and the resultant is showing in **Fig. 8-(d)** Then, following Eq. (3), the secret bits are embedded in the image as shown in **Fig. 8-(e)**. Finally the final stego image block is constructed by the reverse of central prediction scheme as shown in **Fig. 9**.

154	**155**	**155**
154	154	155
153	154	155

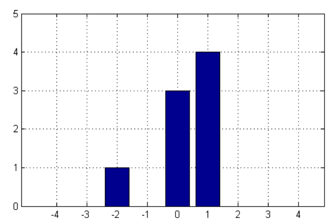
(a) An example of Cover block

0	**1**	**1**
0	154	**1**
-1	0	**1**

(b) Prediction Error block



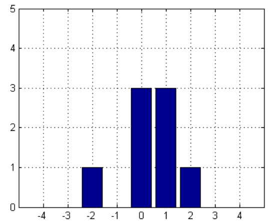
(c) Histogram of original Prediction Error block



(d) Result of Histogram Shifting

0	**1**	**1**
0	154	2
-2	0	1

(e) Resultant of secret hiding



(f) Histogram of Prediction Error after embedding

Fig. 8. The example of our embedding procedure

154	155	155
154	154	156
152	154	155

Fig. 9. Final Stego-block

3.4 Extracting Algorithm

The extracting procedure for the lossless recovery of the cover image and the secret information is similar with the embedded procedure exception the image is stego-image. The extracting procedure is described as follows.

1. Divide the 8-bit gray scale stego image I' of size $M \times N$ into non-overlapping blocks of size $K \times K$.
2. Generate the prediction error block (SB) for each block using the same prediction algorithm as used in the embedding phase in the same sequential order as given in section 3.1.
3. Scan the block and extract the embedded secret data by the following rule:

$$s' = \begin{cases} 0, \ if \ SB_j = M_1 \\ 0, \ if \ SB_j = M_2 \\ 1, if \ SB_j = M_1 + 1 \\ 1, if \ SB_j = M_2 - 1 \end{cases} \tag{4}$$

The extracted bits are concatenated into the main bit stream s' to form the secret data. In this case of M_1 and M_2, M_1 and M_2 are the received peak and zero points for each block which are compressed using arithmetic coding and sent as a secret key.

4. Remove the secret message from the block SB to recover the original image by using the following rule:

$$SB'_j = \begin{cases} SB_j + 1, if \ SB_j = M_1 - 1 \\ SB_j - 1, if \ SB_j = M_2 + 1 \\ SB_j, \quad otherwise \end{cases} \tag{5}$$

5. Now shifting the histogram back for the rest of the error values according to the following equation:

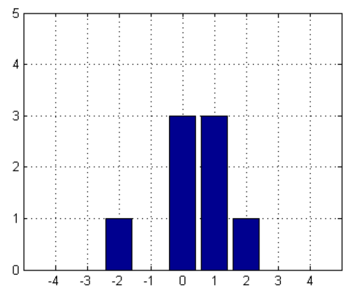
$$SB''_j = \begin{cases} SB'_j + 1, if\ SB'_j \in (m_1, M_1) \\ SB_j - 1, if\ SB'_j \in (M_2, m_2) \\ SB'_j\ , \quad otherwise \end{cases} \tag{6}$$

6. If the embedding procedure was followed '*t*' times, i.e. multi-level embedding was done, then, the steps 3-6 are repeated for '*t*' times and with each iteration the value of the new stego prediction error block (*SB*) is updated as: $SB_j' = SB_j''$.
7. Once all the blocks are restored, following the inverse prediction transformation the original image is constructed.

Following the example of embedding procedure, we will describe the complete extraction procedure. The stego-image generated after in example stated in embedding procedure shown in **Fig. 8** and **Fig. 9**. Keeping the central pixel unchanged we calculate the predictive difference values and generate the histogram as shown in **Fig. 10-(a)** and **10-(b)**, respectively. Now to perform extracting operation the decoder uses the overhead information of two peak and zero pairs (M_1, M_2)=(0, 1) and (m_1, m_2)= (-2, 2) for the block. The pixels are processed sequentially and according to Step 3 of Section 3.3, the secret bits *'0'* for the prediction error pixels equal to 0 and 1 and secret bits '1*'* for pixel values equal to -1 and 2 are extracted. So the random secret bits finally extracted are 0, 0, 0, 0, 1, 0, 0. After this the histogram is shifted back to its original shape **Fig. 10-(d)** reconstructing the original prediction error blocks as well **Fig. 10-(c)**. Finally the original image is recovered by inverse prediction algorithm.

0	1	1
0	154	2
-2	0	1

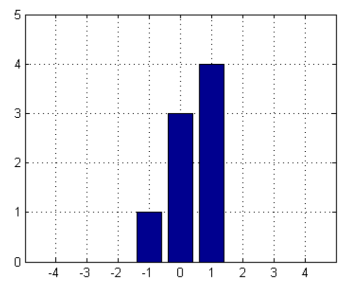
(a) Prediction Error block



(b) Histogram of prediction error block

0	1	1
0	154	1
-1	0	1

(c) The resultant of secret hiding



(d) Histogram of original prediction error block after data extraction

Fig. 10. The example of our extracting procedure

4. Experimental Results and Discussions

We will demonstrate the experimental results of our approaches and give some discussion about the exception problem of overflow/underflow and overhead in this section. The detail comparison between our approaches and previous methods, histogram-based proposed by Ni et al. in 2006 and multilevel data hiding scheme proposed by Lin et al. in 2008, are given in Section 4.1. The discussion of exception problem, overflow/underflow, and overhead are shown in Section 4.2 and 4.3, respectively.

4.1 Performance Of Embedding Capacity And Image Quality

In this subsection, we show the performance of our approaches for one level and multilevel, which indicates that the embedded procedure is executed with one and '*t*' times. In our experimental results, we have used seven commonly tested images of size 512×512 as shown in **Fig. 11** as the cover images. The secret bit-stream in our algorithm was generated using the pseudo random number generator of Matlab compiler with identical probabilities for bit '1' and bit '0'. For evaluating the performance, we use the estimation function of the estimation function of peak-signal-to-noise-ratio (PSNR) and MSE, which is defined as Eq. (7) and Eq. (8).

$$\text{PSNR}(\text{db}) = 10 \times \log_{10}\left(\frac{255^2}{MSE}\right) \quad (7)$$

$$MSE = \frac{1}{M \times N} \sum_{x=1}^{M} \sum_{y=1}^{N} (I(x,y) - I'(x,y))^2 \quad (8)$$

where, M and N denote the width and height of the image, and $I(x, y)$ and $I'(x, y)$ are the pixel values of cover image and stego-image, respectively.

In our experimental results, for both the proposed schemes, we simulated the algorithm with block size of 3×3 pixels. The performance of our method depends on the peak point in the prediction errors' histogram in each block. Here, we have found by experimentation that best performance is given by the block size of 3×3. The reason behind this is that in a small size block the correlation among the pixels is large to have better embedding capacity. Here, we have compared our results with Ni et al.'s scheme and the multilevel scheme proposed by Lin et al. in 2008**.**

Table 1 shows the comparison results with some of the other histogram shifting methods like Ni et al. [8], Lin et al. [15] and Yang-Tsai scheme [25]. Note, only one layer embedding procedure is used in compared schemes. From this table, we can know that the embedding capacities (in bits per pixel) of the images with different texture complexities is much higher as compared to [8], [15], and [25] with higher PSNR values (in dB). The embedding capacity of the proposed scheme is equal to the number of pixels associated with the peak points of the blocks in the difference image. So, the mechanism of prediction plays a very crucial role in the process.

In **Table 2** we have compared our results with two prediction schemes presented in section 3.1.1 and 3.1.2. By proposing to choose different peak and zero pair for each block the embedding capacity is increased and by not changing the causal pixel values, unlike Lin et al., the image quality is maintained at a high PSNR. **Table 2** and **Table 3** compare the PSNR values and the hiding capacity of the proposed scheme at various hiding levels with Lin et al.'s scheme, respectively. The image quality decreases after performing multiple-layer embedding to achieve high embedding rate.

Fig. 12 shows that the visual quality of the "Tiffany" stego image is maintained and meets the imperceptible requirement at high hiding capacity after various hiding levels. **Fig. 13** shows the comparison of embedding capacity in bpp versus image quality in PSNR of the proposed scheme with that of the recent reversible data hiding schemes namely Ni et al. [8], DE [9] and Lin et al.'s scheme[15] for the various grayscale image. It can be clearly seen from the figure out that the PSNR value of the proposed schemes is about 10~15dB higher dB than the other schemes, and embedding capacity is also higher about 1~1.3bpp than others. That represents that the proposed achieves relatively higher hiding capacity and lower image distortion than others schemes.

4.2 Lower Bound Of PSNR Of Stego Image

In our scheme, we also adopt PSNR (Refer to Eq. (7)) to measure the image quality of the stego image generated after data hiding and investigate the lower bound of the image quality of the stego image. Assume that data hiding level is 1and the block size is set to 3×3. In our case we embed into 8 pixels out of a total of 9 pixels in each block leaving the central pixel as non-embeddable. So in the worst case at most 8 pixels out of 9 may get incremented or decremented by 1. Hence, the distortion in each block can be depicted as 8, i.e. all 8 pixels getting changed by 1. So, the Mean Square Error can be given by

$$MSE = \frac{1}{9}\sum_{i=1}^{8} 1 = \frac{8}{9} = 0.88$$

Therefore the Lower Bound of the stego image can be given as:

$$PSNR = 10 * \log_{10}\left(\frac{255^2}{8/9}\right) \approx 48.65$$

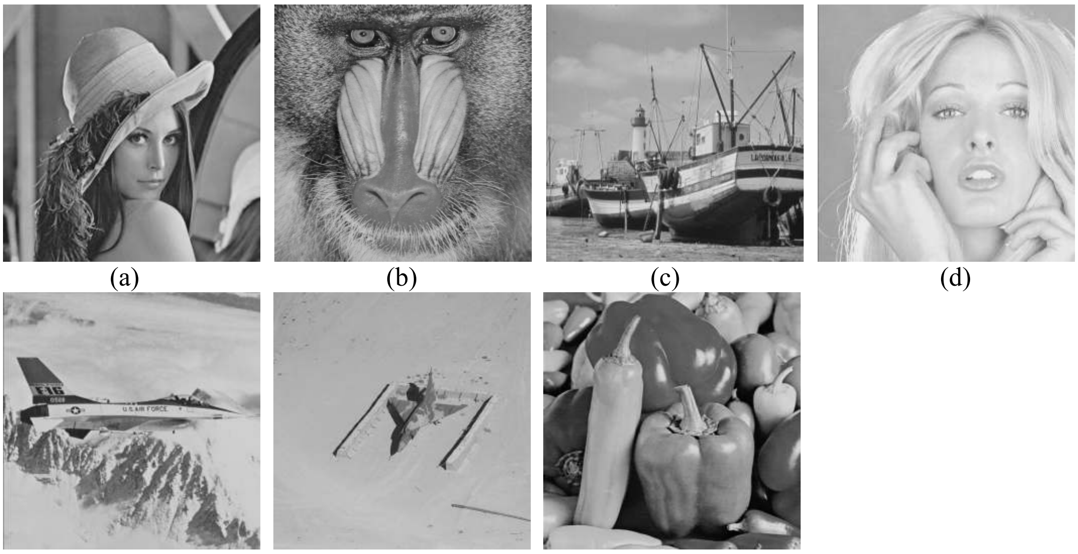
Hence we can theoretically prove that the lower bound of PSNR of our proposed scheme for the 1st level hiding is 48.65 dB which is further proved with the help of experiments in the next section. The lower bound of the pixel is greater than the previous work of Ni et al. as well as Lin et al.'s Multi-level.

4.3 Overflow And Underflow

In the proposed scheme sometimes there will be cases of overflow and underflow of pixel values due to histogram shifting procedure, i.e. the specified pixel value might be -1 or 256 after the embedding procedure is done. It is of couse only in the case of pixel value at, either 0 or 255 when meeting underflow or overflow for histogram shifting. It must be definitely excluded so as to fulfill the reversibility. So, in order to avoid overflow and underflow problem a location map stating the locations of all such pixels need to be stored and a location map is created for the purpose. This location map is either compressed and sent along with the secret key or embedded in the LSB of the stego image. Fortunately, the phenomenons of underflow and overflow are rare for our algorms in use. **Table 4** lists the total number of cases when going through multi-level hiding against the overflow or underflow. It can be observed from the table that even for hiding level from 1 to 12, most the test images pass it, only the image of Pepper gives rise to the situations from level 2 to 12. In other words, we can say that such a situation rises for a very few cases and the size of overhead information is very small.

4.4 Overhead Information

We have restricted the number of maxima minima pairs to 2 in order to save upon the overhead information to be sent. For two pairs, it is totally comsumed 32 (= 4×8) bits in saving overhead inforamtion. In our proposed scheme, we can use the compression tools, i.e. arithmetic coding, Run-length approach, or JBIG, to compress the maxima minima pairs which are transmitted as overhead information and serves as a secret key. In case of the arithmetic coding, the entire set of maxima minima pairs is then encoded into a single number of 'n', $0.0 \leq n \leq 1.0$. We found that 2 pairs sufficiently give high embedding capacity and we don't need to go for more than 2 for a small block of 9 or 16 pixels. Also unlike in Ni et al.'s scheme, the location of the pixels need to be stored if no zero point is encountered, in the proposed method the case can never arrive as we apply our scheme on the block by block basis and we always encounter the zero points thus saving upon this extra information. Finally, we conclude that the overhead information of maxima minima pairs of being a single number is negligible.



(e) (f) (g)

Fig. 11. Tested Images: (a) Lena; (b) Baboon; (c) Boat; (d) Tiffany; (e) Airplane; (f) Jet; (g) Pepper.

Table 1. Comparison of hiding capacities and PSNR for tested images of our proposed scheme with other schemes. Note, only one layer is used in all the comparison schemes.

	Ni et al.'s histogram-based [8]		Lin et al.'s multilevel embedding [15]		Yang- Tsai scheme [25]		Our proposed scheme			
							Central prediction		MED prediction	
	PSNR	Capacity	PSNR	Capacity	PSNR	Capacity	PSNR	Capacity	PSNR	Capacity
Lena	48.20	5,460	48.14	65,348	49.05	99,873	52.74	111,513	49.29	112,850
Airplane	50.26	59,562	48.73	101,326	49.11	104,903	52.28	191,781	49.23	165,998
Tiffany	48.13	10,087	49.04	62,411	48.89	82,650	52.44	117,692	49.48	110,689
Jet	48.70	59,979	48.71	69,941	49.14	107,914	52.39	125,944	49.26	121,221
Baboon	48.20	5,421	48.06	42,484	48.39	30,636	55.03	79,245	51.62	79,401
Boat	48.20	7,301	49.59	56,713	48.72	65,692	52.71	110,315	49.82	104,678
Pepper	48.17	5,715	45.20	64,632	48.91	85,537	52.70	110,365	49.36	108,842
Average	48.55	21,932	48.21	66,122	48.89	82,458	52.90	120,982	49.72	115,122

Table 2. The average PSNR of Lin et al.'s scheme and our proposed with standard test images by using different hiding levels

Hiding Level	1	2	3	5	9	12
Multi-level	48.67	43.02	39.64	35.28	30.19	27.58
Proposed 1 (Central)	53.55	48.48	45.59	42.12	37.21	34.58
Proposed 2 (MED)	49.91	45.28	42.32	38.30	33.34	30.77

Table 3. The Embedded Capacity and Ratio (bit per pixel) of Lin et al.'s scheme and our proposed with Lena image by using different hiding levels

Hiding Level		1	2	3	5	9	12
Multi-level	Capacity	65,349	115,963	158,815	230,762	346,568	416,882
	Ratio	0.2493	0.4424	0.6058	0.8803	1.3221	1.5903
Proposed 1 (Central)	Capacity	111,513	202,437	279,474	411,514	647,863	821,775
	Ratio	0.4287	0.7783	1.0745	1.5821	2.4908	3.1595
Proposed 2 (MED)	Capacity	100,691	179,919	246,342	356,576	519,237	621,969
	Ratio	0.3841	0.6863	0.9397	1.3602	1.9807	2.3726

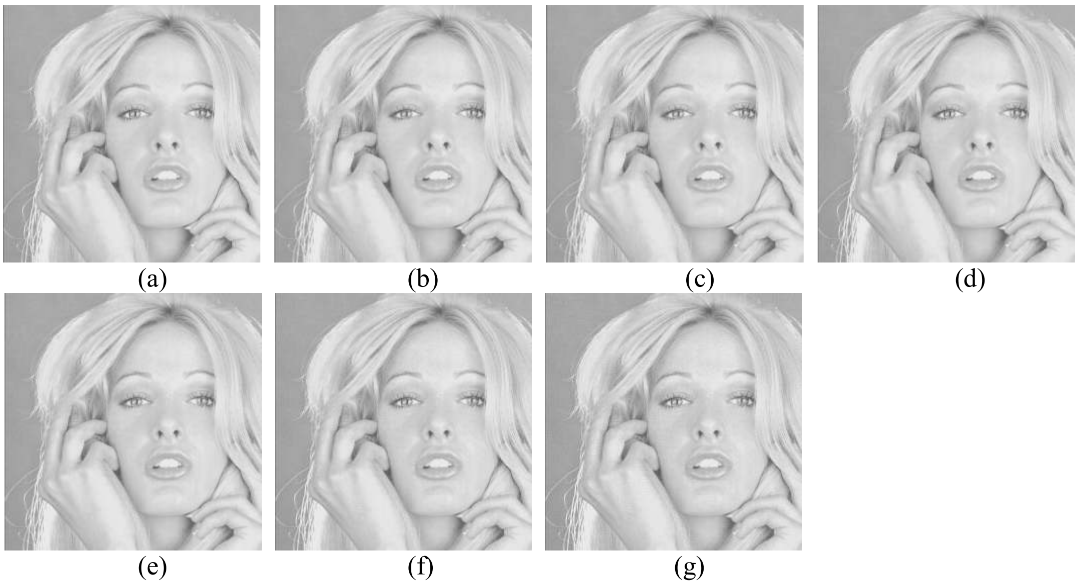


Fig. 12. Comparing the image quality at various hiding levels with Tiffany image: (a) Cover image; (b) Level 1; (c) Level 2; (d) Level 3; (e) Level 5; (f) Level 9; (g) Level 12.

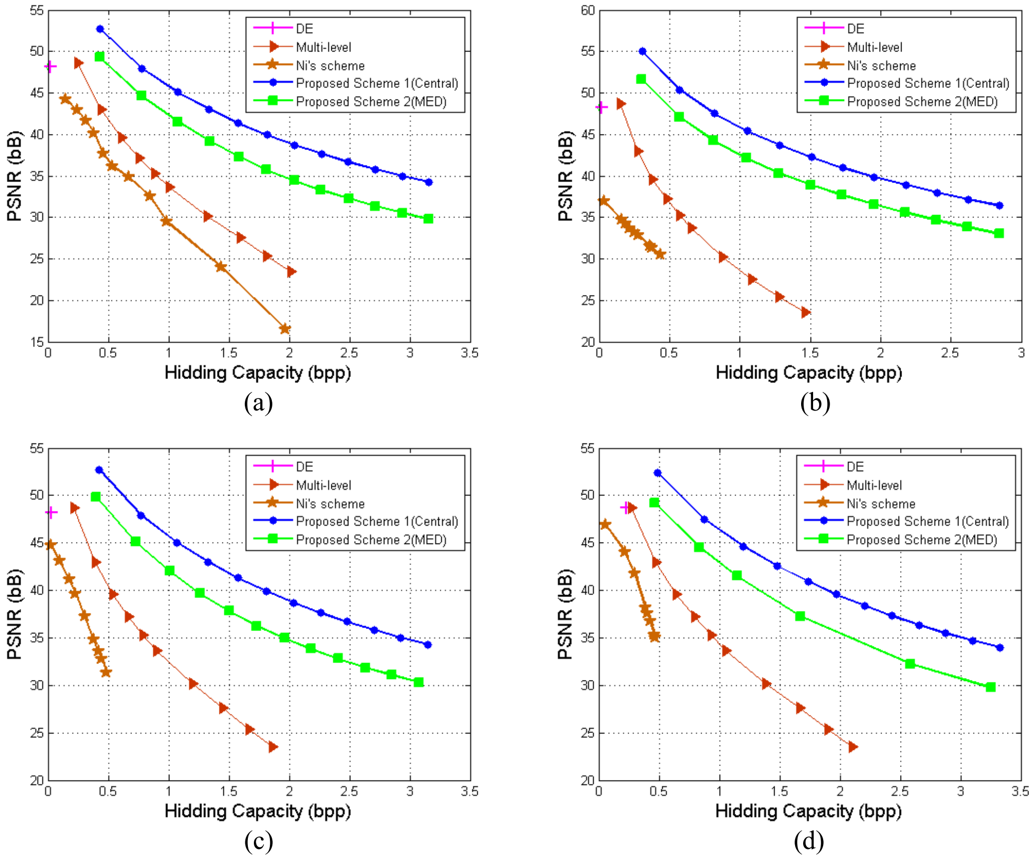


Fig. 13. Comparison of the performance with previous reversible data hiding scheme, Difference Expansion Scheme (DE)[9], Multi-level histogram shifting scheme[15], histogram-based scheme[8], by using various cover images: (a)Lena image; (b) Baboon image; (c)Boat image; (d)Jet image.

Table 4. The bit numbers of Overflow and Underflow with different test images by using our proposed scheme at different hiding level.

Hiding Level / Images	1	2	3	5	9	12
Lena	0	0	0	0	0	0
Baboon	0	0	0	0	0	0
Boat	0	0	0	0	0	0
Tiffany	0	0	0	0	0	0
Airplane	0	0	0	0	0	0
Jet	0	0	0	0	0	0
Pepper	0	2	10	53	278	718
Barbara	0	0	0	0	0	0

5. Conclusion

In this paper, we proposed a novel reversible data hiding technique based on histogram shifting of the prediction errors on the block by block basis to increase the hiding capacity. In our approach, two used predictors, center prediction method and JPEG-LS median edge predictor (MED) are applied to generate the prediction errors that is produced by pixel differencing between predictor and current pixel. The pixels in the difference image creates higher peak points because the pixels within a block are highly correlated in natural images and it therefore has better performances than that of Ni et al.'s, Lin et al. 's schemes and Yang-Tsai scheme. From the experimental results, the proposed scheme outperforms some of the previous works both in terms of capacity and PSNR. The results provided prove that the PSNR value and embedded capacity of the proposed scheme are better than that previous literatures for signal-level and multi-level, and the computation complexity of the proposed scheme is also very small as it just deals with the shifting and searching operations.

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