**Citation for published version**

Fallahpour, M., Megías, D., Shi, Y. Q. (2011). Lossless Image Data Embedding in Plain Areas. Proceeding of SPIE. Media Watermarking, Security, and Forensics III, 7880().

**DOI**
https://doi.org/10.1117/12.877009

# Lossless Image Data Embedding in Plain Areas

Mehdi Fallahpour [a], David Megias[a], Yun Q. Shi[b]
[a]Universitat Oberta de Catalunya Barcelona, Spain
[b]New Jersey Institute of Technology, Newark, USA

## ABSTRACT

This letter presents a lossless data hiding scheme for digital images which uses an edge detector to locate plain areas for embedding. The proposed method takes advantage of the well-known gradient adjacent prediction utilized in image coding. In the suggested scheme, prediction errors and edge values are first computed and then, excluding the edge pixels, prediction error values are slightly modified through shifting the prediction errors to embed data. The aim of proposed scheme is to decrease the amount of modified pixels to improve transparency by keeping edge pixel values of the image. The experimental results have demonstrated that the proposed method is capable of hiding more secret data than the known techniques at the same PSNR, thus proving that using edge detector to locate plain areas for lossless data embedding can enhance the performance in terms of data embedding rate versus the PSNR of marked images with respect to original image.

**Keywords:** Watermarking, image data hiding, prediction.

## 1. INTRODUCTION

Data hiding schemes can conceal additional information in media. Most data hiding schemes distort the original media in order to embed the secret data. Although the distortion is often small and imperceptible, the reversibility is crucial to some sensitive applications. In applications, such as in law enforcement, medical image systems, it is required to be able to reverse the marked image back to the original cover image for legal consideration. In remote sensing and military imaging, high accuracy is demanded. In some scientific research, experimental data are expensive and difficult to be achieved. Under these circumstances, the reversibility of the original media is desired. Reversible data hiding [1,2] is a novel category of data hiding schemes, where at present, there are growing interest in it.

Fridrich et al. [3] introduced a new lossless data hiding method to increase the embedding capacity which works by modifying the least significant bits (LSBs). Their algorithm compresses the least significant bit plane of the cover image and then embeds these compressed data and the embedded data into the cover image. Celik et al. [4] proposed a generalized-LSBs algorithm to improve the performance of Fridrich et al.'s method in terms of capacity, where the quantization residues of the cover image can be achieved after a quantization process and then the CALIC lossless compression algorithm is used to get the compressed residues. The remainder of the compression space is used to embed the secret information. Also [5] proposed a high capacity image steganography model based on variable size LSB insertion. Tian [6] presented a difference-expansion (DE) scheme that divided the image into pairs of pixels that were classified into three groups—expandable, changeable, and nonembeddable—in which information was recorded using a location map. In Tian's method, one hidden bit can be embedded into one of the changeable or expandable pairs. Alattar [7] proposed a generalized version of Tian's scheme to enhance the payload, in which instead of pixel pairs the difference expansion of vectors is used. Also Kamstra et al. [8] have extended Tian's method by using the information in the low-pass band to find appropriate expandable differences in the high-pass band. Recently Kim et al. [15] improved [6], [8] by introducing a new location map and a new embedding method. Chang et al. [9] presented a reversible embedding scheme for side-match vector quantization compressed images. Their method can recover only the side match vector quantization image instead of the vector quantization image. Chang and Lin [10] suggested a completely reversible embedding scheme for vector quantization compressed images. However, the computational cost for their method is high, and is not suitable for real-time applications.

Ni et al. [11] presented a lossless data embedding algorithm based on the spatial domain histogram shifting. In [12] a high capacity lossless technique was proposed by the author based on the relocation of zeros and peaks of the histogram of image blocks to embed the data. Recently, Lin and Hsueh [13] suggested a lossless scheme based on increasing the differences between two adjacent pixels. Among the studies performed on transform domain Xuan et al. [14] reported the remarkable reversible method carried out in the integer wavelet transform domain.

In accordance with to international lossless and near lossless image compression standards, the compression procedure is often composed of creating image prediction. This prediction step usually applies a predictor to estimate the pixel values of an input image. Recently few prediction based data hiding methods have been proposed [16, 17, 18]. Thodi et al. [17] expanded the difference between a pixel and its predicted value in the context of the pixel. Also in [18] a method based on gradient-adjusted prediction (GAP) is proposed by the authors of this paper. This scheme is capable of hiding more secret data with absolutely high PSNR.

The proposed method is based on increasing the differences between pixels of cover image and their prediction values. Increasing the prediction error and modifying the pixels force distortion to the image. Using just plain areas where predictors work more accurately, decreasing the modified pixels and improves the transparency. To use plain areas an edge detector locates the edges and plain areas. The prediction error at which the number of prediction errors is at a maximum is selected to embed the message. The prediction errors in plain areas and larger than the selected error are increased by “1”. Furthermore, the selected prediction error in plain areas is left unchanged and increased by “1” if the embedded bit is “0” and “1”, respectively.

This method is able to embed a huge amount of data (10-100 kb for a 512 x 512 x 8 grayscale image) while the PSNR of the marked image versus the original image is very high (over 40dB). Our experimental study has shown that using edge detector to locate plain areas for embedding enhances the capacity by 7% to 50% as PSNR ranges from 45 dB to 52 dB. In addition, simplicity, short execution time and applicability to almost all types of images are merits of this proposed method.

## 2. PREDICTION ALGORITHM

From the literature on prediction techniques, the gradient-adjusted prediction (GAP) predictor [19] is the state of the art predictor that is used in context-based adaptive lossless image codec (CALIC). The pixel to be predicted is denoted by $x$ (the current pixel), and its predicted value generated by a predictor is denoted by $\hat{x}$. The casual template used in the predictors is shown in Fig. 1, where the shaded area represents the neighboring pixels of the current pixel $x$. For simplicity, *a, b, c, d, e, f, g*, and $x$ also denote both the pixel values and their locations.

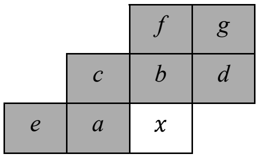


Fig 1. Casual template

**Gradient adjacent prediction (GAP)**

The gradient variations of the adjacent pixels are used for estimating the pixel value. The gradient-adjusted prediction (GAP) algorithm operates on seven neighbors of the current pixel of a cover image $x$. By applying the GAP prediction for $x$, its predicted value $\hat{x}$ can be computed as follows:

```
$d_h = |a - e| + |b - c| + |b - d|$
$d_v = |a - c| + |b - f| + |d - g|$
if ( $d_v - d_h > 80$) {sharp horizontal edge} $\hat{x} = a$
else if ($d_v - d_h < -80$) {sharp vertical edge}$\hat{x} = b$
else {
    $\hat{x} = (a + b)/2 + (d - c)/4$ { smooth area}
    if ( $d_v - d_h > 32$) { horizontal edge} $\hat{x} = (\hat{x} + a)/2$
    if ( $d_v - d_h > 8$) { weak horizontal edge} $\hat{x} = (3\hat{x} + a)/4$
    if ( $d_v - d_h < -32$) { vertical edge} $\hat{x} = (\hat{x} + b)/2$
    if ( $d_v - d_h < -8$) {weak vertical edge} $\hat{x} = (3\hat{x} + b)/4$
}
```

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

## 3. PROPOSED METHOD

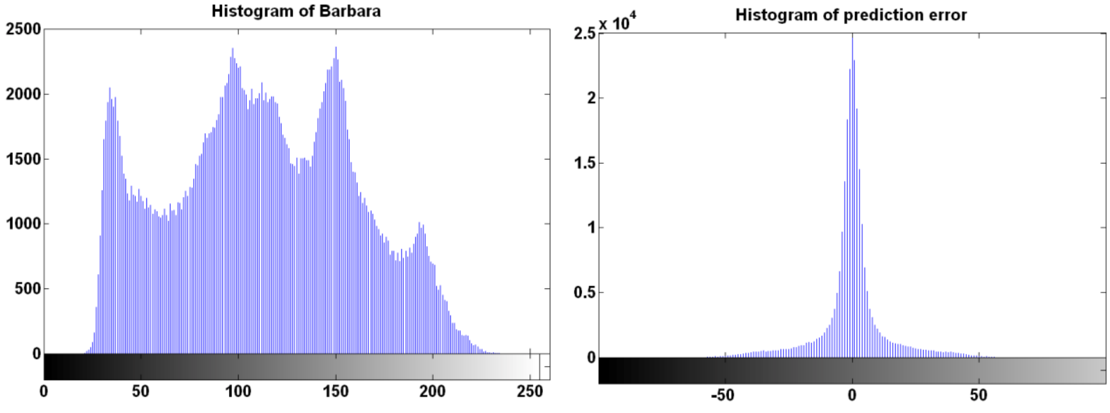
Use of histogram of image for data hiding was first introduced by Ni et. al [11]. Shift all pixels which they are larger than peak of the histogram to prepare a space for embedding secret information is the main idea of [11]. The peak point of the histogram defines the capacity of the scheme. Then in [12, 13, 18] through image tiling, difference between pixels and prediction the data hiding capacity was increased by narrowing the histogram. The key point in the histogram based algorithms is that the narrower histogram results in the more capacity for data hiding. This is because a narrower histogram has a higher peak (as shown in Fig 2). Hence it is expected the histogram of the prediction error of an image to be able to accommodate more data than the histogram of the image itself. For example available capacity for Barbara image by using histogram of prediction error, Fig. 2(b), is about 10 times than using histogram of original image, Fig. 2(a). In all these schemes [11, 12, 13,18] to prevent error in extracting the embedded data and reversibility, all values larger than peak point have to be incremented which increases the distortion. The aim of proposed scheme is decrease the amount of modified pixels to improve transparency by keep their values in the edges of the image which leads us to a better capacity and better transparency.

To locate edges let define $E(x)$ of current pixel of the image $x$ as below

$$E(x)=Max(a,b,c,d)-Min(a,b,c,d) \qquad (I)$$

In [5] Lin and Chen used this equation to compute the capacity of embedding information however here is just used to estimate the edges.

This method contains embedding and extracting procedures. The embedding process includes computing the prediction errors and edge values as well as embedding the information bits in the shifted prediction errors. The data extraction process is the reverse of data embedding.



(a) (b)

Fig2. Histogram of Barbara image (a) original (b) prediction error

### 3.1 Embedding

GAP is used in this algorithm since in general prepares better prediction so narrower prediction error is achievable. However the drawbacks of Gap prediction are using real (not integer) numbers and more computation time.

1) By using GAP a prediction of the cover image is derived. Steps (2-8) are then performed on this predicted image.

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

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

4) To prevent overflow and error in extracting the embedded data, the positions of all pixels with a value of 255 are recorded as side information. Also steps 5, 6 and 7 are carried out for elements with $I_{i,j} < 255$.

5) Calculate $E(x)$ and if $E(x)$ is less than a $T$ (threshold) continue the embedding steps otherwise we do not change the value of current pixel and marked pixel will be the same as original one and we have to continue the all embedding steps for next pixel.

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

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

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

Thus with the above embedding steps, the marked pixel $I_{i,j}{}'$ with the embedded bit $b_k$ can be formulated as:

$$I_{i,j}{}' = \begin{cases} \hat{I}_{i,j} + e_{i,j} + 1 & \text{If } E(x) < T \text{ and } e_{i,j} \geq S+1 \\ \hat{I}_{i,j} + e_{i,j} = I_{i,j} & \text{If } E(x) \geq T \text{ and } e_{i,j} \geq S+1 \\ \hat{I}_{i,j} + e_{i,j} + b_k & \text{If } E(x) < T \text{ and } e_{i,j} \in [S, S+1) \\ \hat{I}_{i,j} + e_{i,j} = I_{i,j} & \text{If } E(x) \geq T \text{ and } e_{i,j} \in [S, S+1) \\ \hat{I}_{i,j} + e_{i,j} & \text{If } \quad e_{i,j} < S \end{cases}$$

Threshold, *T*, determines the edges, for example high threshold results in sharp edges. Hence based on demands threshold should be chosen. Based on *E(x)* we cannot judge hundred percent about pixels are eligible for embedding or not. I.e. a few percent of pixel that are suitable for embedding do not pass the $E(x) < T$ condition and finally we do not use them for embedding but the very important point is totally better capacity and transparency will be achieved where experimental results prove that.

Note that, depending on the prediction matrix, not every prediction error can be used for bit embedding. In fact, in GAP the two top-most rows and the two left-most columns of a cover image are not used for hiding data. To obtain original values of the pixels and the secret information these rows and columns are reserved and are the same in the cover and marked images. The most right column is not predictable by GAP since for pixels in this column there are no neighbors to *d*, *g*. Thus this column is not useful for embedding secret bits. The gray value of *S* and positions of all pixels with value 255 will be treated as side information that need to be transmitted to the receiving end for data retrieval. It is worth to mention that for 8 gray-scale natural images we have very rarely pixels with value equal to “0” or “255”. Also as GAP is good predictor almost always the value of *S* is “0”. Thus in practical applications we do not need side information.

It is worth noting that data embedding at the encoder and extraction at the decoder follows the raster scan order.

### 3.2 Detection

The following process is used for extracting the secret message from a marked image and losslessly recovering the cover image by using the side information. Let $x'_{i,j}$ be the received image at the decoder.

1) As the pixels in the two top-most rows and two left-most columns do not carry any secret data, they can be easily restored by $x_{i,j} = x'_{i,j}$ for $i < 3$ or $j < 3$. Starting from the pixel $x'_{3,3}$, the following steps (2-6) are carried out for each pixel completely and then iterated for the next pixel. If $x_{i,j}$ was recorded as side information then $x_{i,j} = x'_{i,j}$ and steps (2-6) are carried out for the next pixel.

2) The prediction pixel $\hat{x}_{i,j}$ and $E(x)$ of $x_{i,j}$ are obtained by the prediction algorithm and equation (I) by using its adjacent pixels, which have already been restored.

3) If $E(x) < T$ the detection process should be continued for current pixel by perform next steps. Otherwise the detection step should continue from step 1 for next pixel, also the restored pixel image will be the same as marked image.

4) If the embedded PE, $e''_{i,j} = x'_{i,j} - P_{i,j}$, is inside the interval $[S+1$ , $S+2)$, then it is concluded that the embedded data bit was “1”. In this case, $e''_{i,j}$ should be decreased by one to obtain the modified PE, $e'_{i,j} = e''_{i,j} - 1$. If $e''_{i,j}$ is inside the interval $[S$ , $S$+1) the embedded data bit was “0” and $e'_{i,j} = e''_{i,j}$, otherwise there was no embedded data bit and again $e'_{i,j} = e''_{i,j}$ .

5) If $e'_{i,j} \geq S$+2 then prediction error $e_{i,j}$ equals to $e'_{i,j} - 1$, otherwise $e_{i,j} = e'_{i,j}$ .

6) Finally, $e_{i,j}$ should be added to the prediction value $\hat{x}_{i,j}$ to recover original cover image pixel, $x_{i,j} = \hat{x}_{i,j} + e_{i,j}$ , which is used for next pixels.

Fig. 3 shows an example of a 2×2 grey scale image. The encoder scans the cover image, Fig. 3(c1), in the raster-scan order pixel by pixel to compute the predicted pixels, Fig. 3(c2), and edge value, Fig. 3(c3), by equation (I) from the cover image pixels. Assume the bit to be embedded is “1”. Suppose the obtained $S$ is equal to “0”. The encoder scans the PE, Fig. 3(c4), matrix and all elements equal to or larger than 1 and with edge value less than threshold (in this case $T$=5) are increased by one, Fig. 3(c5), and then the modified prediction errors in interval [0, 1) are chosen for embedding data. The secret data bit is ”1” also edge value related to pixel with prediction value equals zero is less than threshold so the modified prediction value is added by one, Fig. 3(c6). Marked image, Fig. 3(c7), is obtained by adding the embedded prediction errors, Fig. 3(c6), to the predicted pixels, Fig. 3(c2).

The decoder scans the marked image, Fig. 3(d1) and does all the steps pixel by pixel with the following rules: Based on the restored cover image pixels, Fig. 3(d7), the prediction pixel value, Fig.3(d2), and edge value, Fig.3(d3) are computed,. If the embedded PE, Fig. 3(d4), is in [0, 1) and edge value is less than threshold the embedded data bit will be “0” and the modified PE Fig. 3(d5), is equal to the embedded PE, Fig. 3(d4). If the embedded PE is in [1, 2) and edge value is less than threshold the embedded data bit will be “1” and to obtain the modified PE, the embedded PE should be decremented. In case the modified PE is equal to or larger than 2 and edge value is less than threshold, prediction error, Fig. 3(d6), will be obtained by decrementing the modified PE by one, otherwise PE will be equal to the modified PE. Finally, the restored cover image pixel, Fig. 3(d7), is computed by adding PE, Fig. 3(d6), to the prediction pixel, Fig. 3(d2).
It is clear that all value with edge value $E(x)$ equal or greater than threshold will not be changed.

## 4. EXPERIMENTAL RESULTS

The Fallahpour’s [18], Kim et al.’s [15], Lin and Hsueh’s [13], Xuan et al.’s [14] and proposed algorithms were tested on general test images (512 × 512 × 8 greyscale image).

This comparison verifies that the proposed method is capable of hiding more secret data than almost all methods mentioned in the literature and at the same being above the imperceptible visual distortion of 40dB. In addition, the use of edge detector improves PSNR, i.e. reduces the distortion. The experimental results obtained with this method show that the embedded data remains invisible, besides no visual distortion can be perceived.

Table 1 reports the experimental results obtained by using whole image without considering edge detector, and results obtained by embedding data into plain areas which are located by edge detector and a threshold. With the main peak at the center, in the Right Shifted type, $S$ is equal to “0” and the prediction errors larger than or equal to “1” are incremented by one and the secret bits are embedded in [0,1). In the Left Shifted type the prediction errors smaller than “0” are decremented by one and the embedded bits will be at the prediction errors of [–2,–1). Thus, in Right-Left (RL) Shifted type, Right Shifted and Left Shifted types are used simultaneously. The table shows that RL-shift of all prediction types have almost double the capacity of the right shift type.

As the prediction error is usually very small, the proposed method is capable of producing high quality marked images. Experimental results of this study exhibit that by increasing the threshold, $T$, capacity and distortion are increased simultaneously. I.e. by increasing the threshold embedder gets permission to use more pixels. So based on demands and application the threshold have been chosen. For example in Fig.4 and Fig. 5 threshold for Barbara is equal to “10” and for Mandrill is “30” to show different range of threshold for different images.

$$\underset{(c1)}{\begin{array}{|c|c|}\hline 3 & 4\\\hline 7 & 7\\\hline\end{array}}\quad \underset{(c2)}{\begin{array}{|c|c|}\hline 3 & 3\\\hline 4 & 5\\\hline\end{array}}\quad \underset{(c3)}{\begin{array}{|c|c|}\hline 4 & 3\\\hline 6 & 7\\\hline\end{array}}\quad \underset{(c4)}{\begin{array}{|c|c|}\hline 0 & 1\\\hline 3 & 2\\\hline\end{array}}\quad \underset{(c5)}{\begin{array}{|c|c|}\hline 0 & \mathbf{2}\\\hline 3 & 2\\\hline\end{array}}\quad \underset{(c6)}{\begin{array}{|c|c|}\hline \mathbf{1} & 2\\\hline 3 & 2\\\hline\end{array}}\quad \underset{(c7)}{\begin{array}{|c|c|}\hline 4 & 5\\\hline 7 & 7\\\hline\end{array}}$$

$$\underset{(d1)}{\begin{array}{|c|c|}\hline 4 & 5\\\hline 7 & 7\\\hline\end{array}}\quad \underset{(d2)}{\begin{array}{|c|c|}\hline 3 & 3\\\hline 4 & 5\\\hline\end{array}}\quad \underset{(d3)}{\begin{array}{|c|c|}\hline 4 & 3\\\hline 6 & 7\\\hline\end{array}}\quad \underset{(d4)}{\begin{array}{|c|c|}\hline 1 & 2\\\hline 3 & 2\\\hline\end{array}}\quad \underset{(d5)}{\begin{array}{|c|c|}\hline \mathbf{0} & 2\\\hline 3 & 2\\\hline\end{array}}\quad \underset{(d6)}{\begin{array}{|c|c|}\hline 0 & \mathbf{1}\\\hline 3 & 2\\\hline\end{array}}\quad \underset{(d7)}{\begin{array}{|c|c|}\hline 3 & 4\\\hline 7 & 7\\\hline\end{array}}$$

Fig. 3 (c1) – (c7) Embedding steps (d1) – (d7) Detection steps

To achieve high capacity a higher number of shifting could be performed and then the PSNR would be decreased. Fig. 4 illustrates the performance comparison of proposed scheme, with the methods reported in [13,14,15,18] for Barbara and Mandrill images in terms of PSNR and payload (bpp: bits per pixel). This figure shows that use of more number of *S*, more peak point results in increasing the capacity and distortion. As shown in Fig. 4, the proposed scheme provides high enough bound of the PSNR (above 40dB) with a quite large data embedding capacity, indicating fairly better performance of this method.

In Fig 5, the horizontal axis represents PSNR while vertical axis the increased data embedding rate in % achieved by embedding data only to plain area over by embedding data to whole image. Clearly, using edge detector to embed information into plain areas significantly improves the capacity under the same PSNR. Our experimental study has shown that as PSNR is 52 dB the improvement of capacity can be as high as 50%; as PSNR is 48 dB, the improvement is 7% for Mandrill image and 15% for Barbara image.

Table 1. Payload capacities (bits) and PSNR (dB) of the test images for whole image and plain area with various thresholds

| **Image** | | **Mandrill** | | **Lena** | | **Goldhill** | | **Barbara** | |
|---|---|---|---|---|---|---|---|---|---|
| **Threshold** | **type** | **capacity** | **PSNR** | **capacity** | **PSNR** | **capacity** | **PSNR** | **capacity** | **PSNR** |
| **whole** | Right Shifted | 9629 | 51.5 | 28971 | 52.1 | 20837 | 52 | 23816 | 51.9 |
| | Right-Left Shifted | 19277 | 48.5 | 57949 | 49.2 | 41466 | 48.9 | 47363 | 49 |
| T=10 | Right Shifted | 2683 | 60.4 | 21551 | 54.7 | 12358 | 56.3 | 17594 | 56 |
| | Right-Left Shifted | 5427 | 57.5 | 43215 | 51.5 | 24443 | 53 | 34992 | 52.8 |
| T=20 | Right Shifted | 5877 | 56 | 26674 | 53.2 | 18013 | 53.5 | 21035 | 54.6 |
| | Right-Left Shifted | 11851 | 52.9 | 53329 | 50.1 | 35838 | 50.3 | 41776 | 51 |
| T=30 | Right Shifted | 7252 | 54.4 | 27940 | 52.8 | 19585 | 52.7 | 22099 | 53.9 |
| | Right-Left Shifted | 14661 | 51.2 | 55862 | 49.6 | 38985 | 49.5 | 43937 | 50.3 |
| T=40 | Right Shifted | 8004 | 53.5 | 28417 | 52.6 | 20180 | 52.4 | 22636 | 53.4 |
| | Right-Left Shifted | 16135 | 50.4 | 56863 | 49.5 | 40162 | 49.4 | 45056 | 50 |

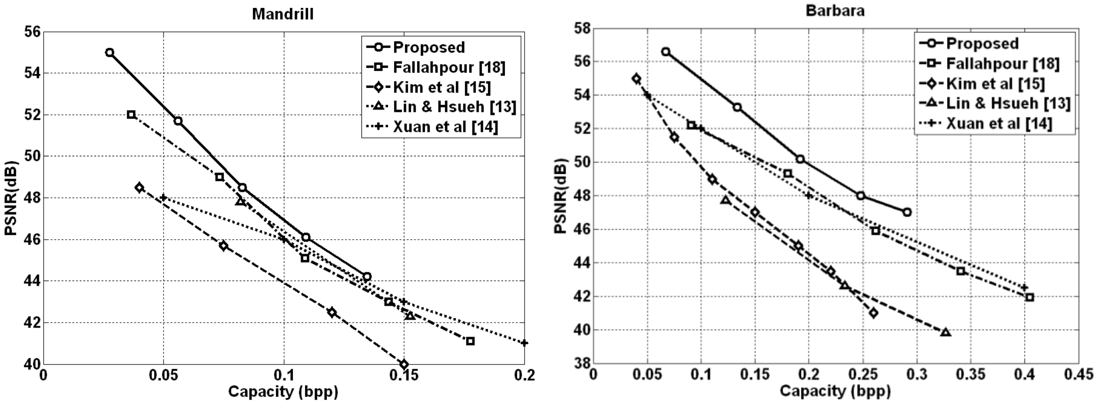


Fig. 4 Comparison among reversible methods in [13, 14, 15, 18] and proposed for Mandrill and Barbara images

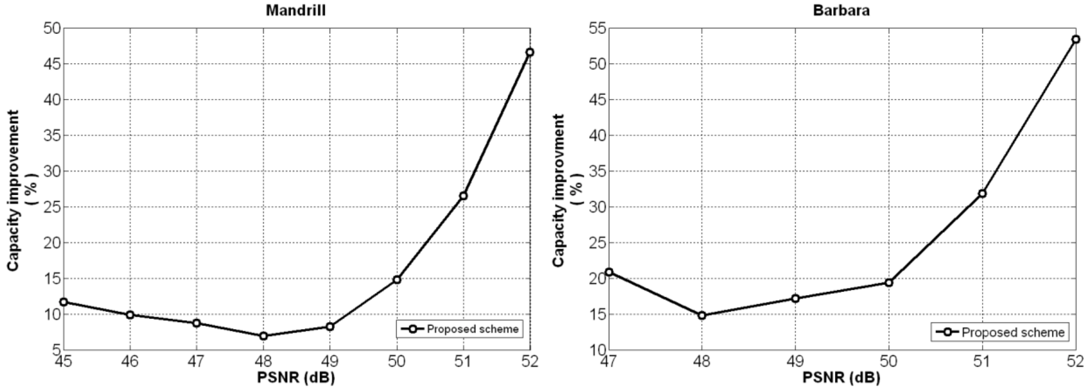


Fig. 5 Improvement data embedding rate in % achieved by embedding data only to plain area over by embedding data to whole image

## 5. CONCLUSION

This paper presents a high-capacity reversible data hiding algorithm which is based on shifting the differences between the cover image pixels and their prediction in plain areas. Large capacity of embedded data (10-100 kb for a 512 x 512 grayscale image), high PSNR (above 40 dB), wide applicability (suitable for almost all types of images), simplicity and short execution time are the key features of this algorithm. Hence, this scheme has advantages to the reported methods [13,14,15,18] in which the algorithms are considered as among the best methods in lossless data hiding.

The high capacity of the proposed method is mainly due to the fact that, the histogram of the prediction errors for normal images is highly peaked. This not only increases the data hiding capacity (owing to narrow density distribution of prediction errors) but also reduces the distortion on the marked image. Furthermore, using plain areas for data embedding further enhances the data hiding performance. Our experimental study has indicated 7-50% increase of embedding capacity by using edge detector for embedding data into plain area as PSNR ranges from 45 dB to 52 dB.

## Acknowledgement

This work is partially supported by the Spanish Ministry of Science and Innovation and the FEDER funds under the grants TSI2007-65406-C03-03 E-AEGIS and CONSOLIDER-INGENIO 2010 CSD2007-00004 ARES.

## 6. REFERENCES

[1] Y. Q. Shi, Z. Ni, D. Zou, C. Liang, and G. Xuan, 2004 “Lossless data hiding: Fundamentals, algorithms and applications,” in Proc. IEEE Int. Symp. Circuits Syst., Vancouver, BC, Canada, (May 2004), vol. II, pp. 33–36.

[2] J. B. Feng, I. C. Lin, C. S. Tsai, and Y. P. Chu, 2006 “Reversible watermarking: current status and key issues,” International Journal of Network Security, vol. 2, No. 3, pp. 161-171.

[3] J. Fridrich, M. Goljan, R. Du, 2001, “Invertible authentication” Proceedings of SPIE Photonics West, vol. 3971, Security and Watermarking of Multimedia Contents III, San Jose, CA, pp. 197–208.

[4] M.U. Celik, G. Sharma, A.M. Tekalp, and E. Saber, 2005, “Lossless generalized-LSB data embedding,” IEEE Trans. Image Process., vol.14, no.2, pp.253–266.

[5] Lee, Y.K., and Chen, L.H., 2000, ‘High capacity image steganographic model’, IEE Proc., Vis. Image Signal Process., 2000, 147, (3), pp. 288–293.

[6] J. Tian, 2003 “Reversible data embedding using a difference expansion,” IEEE Trans. Circuits Syst. Video Technol., vol.13, no.8, pp.890–896.

[7] A. M. Alattar, 2004 “Reversible watermark using the difference expansion of a generalized integer transform,” IEEE Trans. Image Process., vol. 13, no. 8, pp. 1147–1156.

[8] L. Kamstra , J.A.M Heijmans. , 2005: ‘Reversible data embedding into images using wavelet techniques and sorting’, IEEE Trans. Image Process. , 14, (12), pp. 2082–2090.

[9] C.C. Chang, W.L. Tai, C.C. Lin, 2006 ‘A reversible data hiding scheme based on side match vector quantization’, IEEE Trans. Circuits Syst. Video Technol., 16, (10), pp. 1301–1308.

[10] C.C. Chang, C.Y Lin, 2006 ‘Reversible steganography for VQ-compressed images using side matching and relocation’, IEEE Trans. Inf. Forensics Secur., 1, (4), pp. 493–501.

[11] Z. Ni, Y.Q. Shi, N.Ansari, and W. Su, 2006 “Reversible data hiding,” IEEE Trans. on Circuits and Systems for Video technology, 16(3):354–362.

[12] M.Fallahpour, M.H. Sedaaghi, 2007 "High capacity lossless data hiding based on histogram modification," IEICE Transactions on Electronics Express Vol. 4, No. 7 pp.205-210.

[13] C.C Lin, N.L Hsueh, 2007 “Hiding Data Reversibly in an Image via Increasing Differences between Two Neighboring Pixels,” IEICE TRANS. INF. & SYST., Vol.E90–D, NO.12 pp 2053-2059.

[14] G. Xuan, Y. Q. Shi, P. Chai, , X. Cui, Z. Ni, X. Tong,, 2007, "Optimum Histogram Pair Based Image Lossless Data Embedding," Proc. International Workshop on DigitalWatermarking ( IWDW07), Guangzhou, China.

[15] H. J. Kim, V. Sachnev, Y. Q. Shi, J. Nam, and H. G. Choo, 2008 “A novel difference expansion transform for reversible data embedding”. *IEEE Trans. Information Forensics and Security*, 3, 3, 456—465.

[16] D. M. Thodi and J. J. Rodriquez, 2004 “Reversible watermarking by prediction-error expansion,” in Proc. IEEE Southwest Symp. Image Analysis and Interpretation, , pp. 28–30.

[17] D. M. Thodi and J. J. Rodriguez, 2007 “Expansion embedding techniques for reversible watermarking”, IEEE Transactions on Image Processing, vol. 16, no. 3, pp. 721−730.

[18] M. Fallahpour, 2008 “Reversible image data hiding based on gradient adjusted prediction”, *IEICE Electron. Express*, Vol. 5, No. 20, pp.870-876.

[19] X. Wu, N. Memon, 1997 “Context-based, adaptive, lossless image coding”, IEEE Trans. Commun. 45 (4) 437–444.