# Reversible Data Hiding

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***Abstract*—This paper presents a novel reversible data hiding algorithm, which can recover the original image without distortion from the marked image after the hidden data have been extracted. This algorithm utilizes the zero or the minimum point of the histogram and slightly modifies the pixel values to embed data. It can embed more data as compared to most of the existing reversible data hiding algorithms. A theoretical proof and numerous experiments show that the PSNR of the marked image generated by this method is always above 48 dB, which is much higher than other reversible data hiding algorithms. The algorithm has been applied to a wide range of different images successfully. Some experimental results are presented to demonstrate the validity of the algorithm.

***Key words— reversible (lossless) data hiding, watermarking, histogram modification***

## I. INTRODUCTION

Data hiding is referred to as a process to embed useful data (representing some information) into a cover media. In certain applications, the embedded data are closely related to the cover media, such as authentication. In this type of application, invisibility is the major requirement. In most cases, the cover media will experience some distortion due to data hiding and cannot be inverted back to the original media. That is, some permanent distortion exists even after the hidden data have been extracted. In some applications, such as medical diagnosis and law enforcement, it is desired to reverse the marked media back to the original cover media after the hidden data are retrieved. The marking techniques satisfying this requirement are referred to as *reversible* or *lossless* data hiding techniques.

Recently, some reversible marking techniques have been reported in the literature. The first method [1] is carried out in the spatial domain. It uses modulo 256 addition to embed the hash value of the original image. Another spatial domain technique was reported in [2] that losslessly compresses some selected bit-plane to leave space for data embedding. There also exists a reversible marking technique in the transform domain [3], which is based on the lossless multiresolution transform and the idea of patchwork. These techniques aim at authentication, instead of data embedding. As a result, the amount of hidden data is quite limited. The capacity of method [4] is also very limited except it exhibits some robustness against high quality JPEG compression. The first reversible marking technique that is suitable for a large amount of data embedding was presented in [5]. While it is novel and successful in reversible data hiding, the payload is still not large enough. From what is reported in [5], the estimated capacity ranges from 3k bits to 24k bits for a $512 \times 512 \times 8$ grayscale image. Another problem with the method is that when the capacity increases, the visual quality will drop severely. The method [6] based on the integer wavelet transform is the most recently proposed reversible data hiding technique that can achieve a quite large capacity. However, the PSNR of the marked image versus the original image is low due to the histogram modification applied in its pre-processing.

In this paper, we propose a new reversible data embedding technique, which can embed a large amount of data (5k-60k bits for a $512 \times 512 \times 8$ grayscale image) while keeping high visual quality for all images (the PSNR is guaranteed to be higher than 48 dB). It utilizes the zero or the minimum point of the histogram (defined below) and slightly modifies the pixel value to embed the data. This technique can be applied to virtually all types of images. Up to now, it has been successfully tested on more than 100 images, including medical images. The computation of our proposed technique is quite simple and the execution time is very short.

The rest of the paper is organized as follows. The proposed algorithm is introduced in Section II. Some experimental results and conclusions are presented in Sections III and IV, respectively.

## II. ALGORITHM

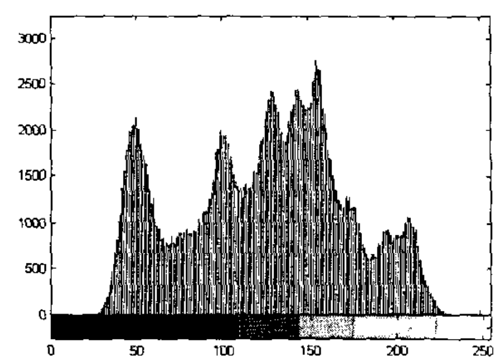


Figure 1: Histogram of Lena image.

We use the "Lena" image as an example to illustrate our algorithm. For a given grayscale image, say, the Lena image

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(512 × 512 × 8), we first generate its histogram as shown in Figure 1.

**A. Embedding algorithm:**

1. In the histogram, we first find a *zero point*, e.g. 255, i.e., no pixel assumes the gray value of 255. Then we find a *peak point*, e.g. 154, i.e., a maximum number of pixels assume the gray value of 154. The objective to find the *peak point* is to increase the embedding capacity as large as possible.
2. The whole image is scanned. The gray value of pixels with gray value between 155 and 254 is incremented by "1". This step is equivalent to shifting the range of the histogram [155,254] to the right by 1 unit, leaving the gray value 155 empty.
3. The whole image is scanned once again. Once a pixel with gray value of 154 is encountered, we check the data to be embedded. If the to-be-embedded bit is "1", the pixel value is added by 1. Otherwise, the pixel value is kept intact.

In this way, we complete the data embedding process. The capacity of this algorithm equals to the maximum number of pixels obtained in Step 1.

Figures 2 and 3 are the original and the marked Lena image, respectively. Figure 4 is the histogram of the marked image.

Figure 2: Original Lena image.

Figure 3: Marked image (PSNR=48.2 dB).

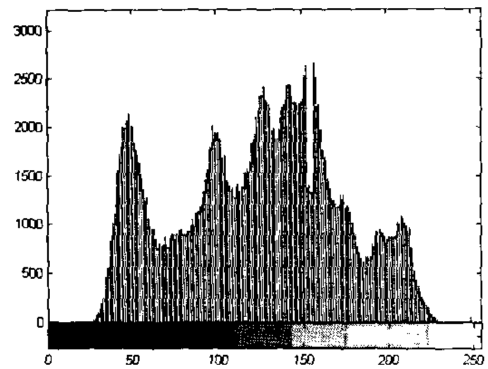


Figure4: Histogram of marked Lena image.

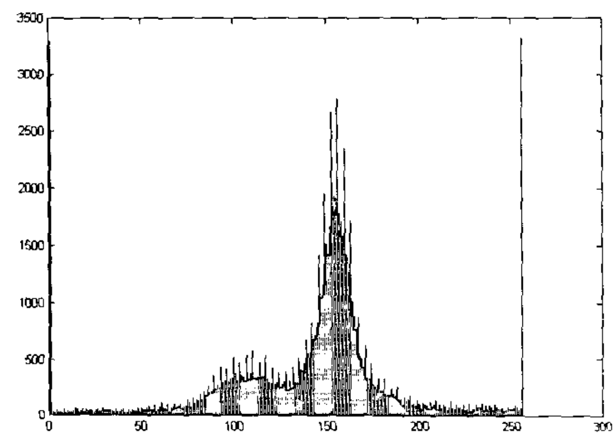


Figure 5: histogram of one medical image (Note that two huge peaks, located at 0 and 255, are 164683 and 20739, respectively. They have been scaled down on purpose due to the page limit.)

Some comments:

1. In very rare cases, we cannot find the *zero point* in a histogram. For instance, the histogram shown in Figure 5 has no *zero point*. We can then use the *minimum point* instead of the *zero point*. For instance, in the above histogram, the gray value 7 is assumed by only 23 pixels. This number of 23 is the minimum number since any other gray value will be assumed by more than 23 pixels. Then the gray value and the coordinates of the *minimum point* are recorded as an overhead part of the embedded data. This book-keeping information will be used later to recover the *minimum point* after the data retrieval.
2. If there are multiple pairs of *zero points* and *peak points*, obviously, it is possible to further increase the payload by adding complexity to this algorithm. For simplicity, however, in our experiments at most two pairs of *zero points* and *peak points* are used in

the above embedding algorithm. For instance, in the experiment with the lena image, we used two pairs of *peak and zero points*, thus achieving a payload of 5460 bits.

3. If the gray value of *zero point* is greater than that of the *peak point*, then adding by "1" is used in Step 2. Otherwise, subtracting by "1" is used in Step 2. That is, the shifting in histogram is "two-way".
4. The gray value of the *zero point* and the *peak point* will be treated as side information that needs to be transmitted to the receiving side for data retrieval.

**B. Data retrieval algorithm:**

For simplicity, only the case of one pair of *zero point* and peak point is considered here.

1. The whole marked image is scanned. Once the gray value of the maximum point is met, if the value is intact, e.g., 154, the "0" is retrieved. If the value is altered, e.g., 155, the "1" is retrieved. In this way, the data embedded can be retrieved.
2. The whole image is scanned once again. Once the pixels whose gray value is between the *peak point* (e.g. 154) and the *zero point* (e.g. 255) is met, the gray value of those pixels will be subtracted by 1. In this way, the original image can be recovered without any distortion.

Note that if the number of the zero points is zero or two, the above data retrieval algorithm can be similarly carried out with only a little alteration.

**C. The lower bound of the PSNR of the marked images**

In our experiments, the PSNR of all marked images is above 48 dB. This can be theoretically proved as follows.

First, the pixels whose gray value is between the *zero point* and the *peak point* will be added or subtracted by 1. In the worst case, all pixels of the image will be added or subtracted by 1, implying that MSE=1. Hence, the $PSNR=10xLog_{10}(255x255/MSE)=48.13$ dB.

Conclusion: The low bound of the PSNR of a marked image is 48.13 dB. This result is much higher than almost all reversible data hiding techniques.

## III. SOME EXPERIMENTAL RESULTS

The proposed reversible data hiding algorithm has been applied to many typical grayscale images and medical images, and has achieved satisfactory results, thus demonstrating its universal capability. Here, the results with commonly used grayscale images and medical images are presented, in particular, the details with the "Airplane" image are provided. The mark signal in the experiment is a binary logo image as shown in Figure 6, equivalent to a binary sequence of 15,903 bits.

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Figure 6: Watermark (a binary image of $171 \times 93$).

Figures 7 and 8 are the original Airplane image ($512 \times 512 \times 8$) and its histogram. The two *zero points* are 0 and 255. The gray values of two *peak points* are 210 and 211, respectively. The numbers of pixels associated with these two *peak points* are 8016 and 8155, respectively. Hence, the capacity is 8016+8155=16,171 bits.

Figure 9 shows other eight marked images. Table 1 summarizes the experimental results. Comparison between the existing reversible marking techniques and the proposed technique in terms of capacity and PSNR is presented in Table 2.

Figure 7: The original Airplane image.

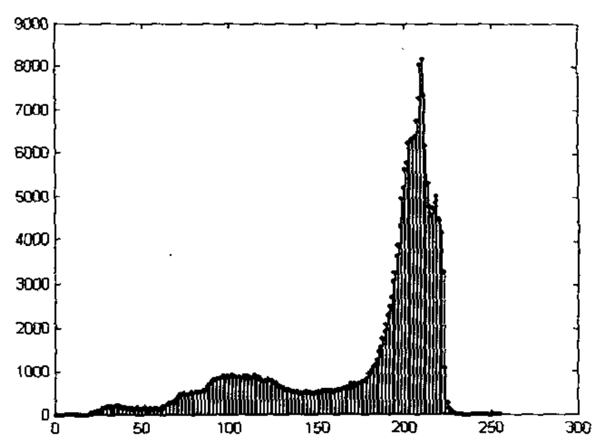
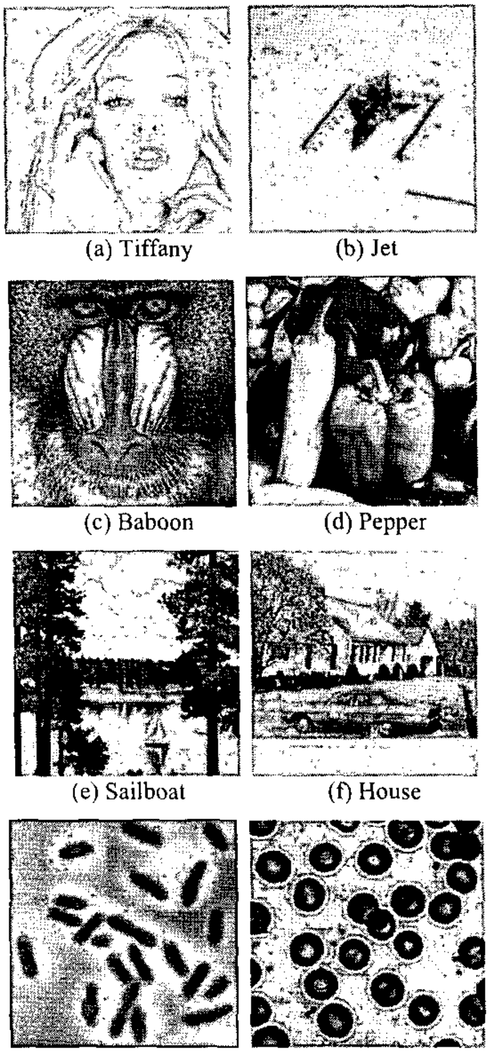



Figure 8: The histogram of the Airplane image.



(a) Tiffany (b) Jet (c) Baboon (d) Pepper (e) Sailboat (f) House (g) Bacteria (h) Blood

Figure 9: Other eight marked images.

Table 1: Some experimental results.

| Images (512x512x8) | PSNR of marked image (dB) | Capacity (bits) |
|---|---|---|
| Lena | 48.2 | 5,460 |
| Airplane | 48.3 | 16,171 |
| Tiffany | 48.2 | 8,782 |
| Jet | 48.7 | 59,979 |
| Baboon | 48.2 | 5,421 |
| Pepper | 48.2 | 5,449 |
| Sailboat | 48.2 | 7,301 |
| House | 48.3 | 14,310 |
| Bacteria | 48.2 | 1,642 |
| Blood | 48.2 | 21,890 |

Table 2. Comparison between three reversible marking methods [3,5,6] and our proposed method.

| Methods | The amount of data embedded in a $512 \times 512 \times 8$ image | PSNR of marked image (dB) |
|---|---|---|
| Macq's | <2,046 bits | Not mentioned |
| Goljan's* | 3k-24k bits | 35 |
| Xuan's | 15k-94k bits | 24-36 |
| Ours | 5k-60k bits | >48 |

*Note: the capacity and the PSNR of Goljan's method are estimated averaged values.

## IV. CONCLUSIONS

Our proposed reversible data hiding technique is able to embed about 5k-60k bits into a grayscale image of $512 \times 512 \times 8$ while keeping the PSNR constantly above 48 dB at the same time. The performance is hence better than most existing reversible data hiding algorithms. Some key features of this algorithm are: 1) PSNR of marked images is proven to be above 48 dB; 2) Capacity of embedded data is quite large (5k-60k bits for a $512 \times 512 \times 8$ image); 3) This algorithm can be applied to virtually all types of images; 4) This algorithm is quite simple, and the execution time is rather short. Hence, it is expected that this reversible data hiding technique will be deployed for a wide range of applications such as in the medical field and law enforcement.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