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A Comparative Analysis on Reversible Watermarking Techniques in Medical Images

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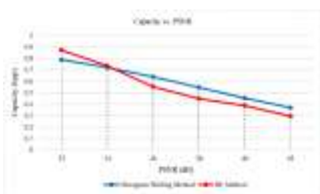
Graphical abstract



Abstract

Digital Image watermarking is usually used for identifying the owner, provider or recipient of an image. Watermarking also can be used for other applications such as copyright protection, fingerprinting, authentication, integrity verification, broadcast monitoring and content description. Reversibility is one of the important aspects in digital image watermarking. It is also known as lossless or invertible watermarking. Compared to conventional watermarking scheme, reversible data hiding restores not only the watermark, but also the original multimedia perfectly, which is a critical requirement for medical and military applications. In this work, after presenting different classifications of reversible methods, two commonly used reversible techniques are explained and their strengths and weaknesses are discussed.

Keywords: Reversible watermarking; difference expansion; histogram shifting

Abstrak

Digital Watermarking Imej biasanya digunakan untuk mengenal pasti pemilik, pembekal atau penerima imej. Watermarking juga boleh digunakan untuk aplikasi lain seperti perlindungan hak cipta, cap jari, pengesahan, pengesahan integriti, pemantauan siaran dan gambaran kandungan. Kebolehbalikan adalah salah satu aspek yang penting dalam imej Watermarking digital. Ia juga dikenali sebagai lossless atau Watermarking dibalik. Berbanding dengan skim Watermarking konvensional, berbalik bersembunyi data mengembalikan bukan sahaja tanda air, tetapi juga multimedia asal dengan sempurna, yang merupakan syarat penting untuk aplikasi perubatan dan ketenteraan. Dalam karya ini, selepas menyampaikan klasifikasi kaedah balik, dua teknik berbalik biasa digunakan dijelaskan dan kekuatan dan kelemahan mereka dibincangkan.

Kata kunci: Watermarking berbalik; perluasan perbezaan; histogram pergeseran

1.0 INTRODUCTION

In watermarking research, we can mention reversible data hiding as a new hotspot. It is also known as lossless or invertible watermarking. Compared to conventional watermarking schemes, in reversible methods not only the watermark (hidden data), but also the original content can be perfectly restored which is critical requirement for medical and military applications. Other applications of reversible watermarking are content integrity authentication, copyright protection and proof of operation of forgery or alteration [1].

In medical applications, by using a reversible data hiding algorithm to embed patient's information as well as diagnostics data in a medical image, both the hidden information and the medical image can be perfectly recovered if needed [2, 3]. To achieve this objective, several approaches may be employed. One approach is to use reversible watermarking methods on the medical image entirely [4-13]. Another one is separating the region of interest (ROI) from the region of non-interest (RONI) and then embedding the watermark into the ROI with a reversible method. The embedding technique for RONI can be reversible [14-19] or non-reversible [20, 21]. In the last mentioned approach, after embedding into the medical image, the ROI recovery information is also embedded into the RONI. Consequently, during extraction, the ROI can be exactly recovered [22-25].

Currently, a dozen reversible data hiding techniques can be seen in the literature. Huang and Chang [26] classified these methods into two main major branches. The first group is based on adjusting the difference value between neighboring pixel pairs that was first proposed by Tian [27]. The second group consists of techniques, which are based on modifying the original image histogram, first proposed by Ni *et al.* [28].

Another group has been proposed by Yeo *et al.* [1] that the reversible watermarking methods divided into 4 main categories. In the first category, the concern is for providing extra space for embedding the watermark information by means of lossless compression techniques such as JBIG1. Two drawbacks of this method are computational complexity and small capacity [2]. One example of this group is the generalized least significant bit (G-LSB) proposed by Celik *et al.* [29], through use of the context-based, adaptive, lossless image codec (CALIC).

The second category is to modify the image coefficients after applying different transforms such as Integer Discrete-Cosine Transform (IDCT) [30] or Integer Wavelet Transform (IWT) [31, 32]. These methods are also computationally complex because of work done in the transform domain.

The third category is based on expanding the difference value between neighboring pixels. As mentioned before, this method was proposed by Tian [27] for the first time and is known as the difference expansion (DE) method. In this method, the location map of expandable difference values and the original LSBs of changeable ones is embedded along with the watermark. Afterwards, Alattar [33, 34] increased capacity by adapting the DE method for color images and considering quad neighbors instead of two adjacent pixels. Kamstra and Heijmans [35] also tried to improve the performance of DE by predicting the position of expandable difference values [36].

The fourth category is based on the modification of the histogram values of the original image [28, 37] or of the differential image histogram [26, 38]. Since most of these methods are spatial-based, they have a lower computational complexity compared to transform domain methods.

The aim of this work is to compare the performance of two of these categories of reversible methods, the difference expansion and histogram modification methods. For this comparison, various parameters have been used such as the quality of watermarked image, hiding capacity, overhead or side information, and computational complexity [26].

The remainder of this paper is arranged as follows. In Section 2, a complete explanation on difference expansion method is presented. In Section 3, a fundamental procedure of the histogram modification method is explained. Comparison of these methods and the description of their advantages and disadvantages are given in Section 4. Finally, in Section 5, the conclusion and summary of this work are provided.

2.0 DIFFERENCE EXPANSION SCHEME

Where the original data is needed after extracting a watermark, reversible method must be used. The first reversible method was introduced by Honsinger *et al.* [39] followed by other researchers who introduced improved reversible methods for better performance.

One of these methods is the difference expansion technique proposed by Tian [27]. In addition to being reversible, this method has a high capacity for embedding and can be used for digital gray image, audio and video.

This method is based on calculating the difference between neighbor pixels values in the horizontal or vertical direction. On the other hand, this method directly follows the IWT concepts by finding the average and difference values of every two adjacent pixels that are regarded as low and high frequency bands in the wavelet transform [1]. This method follows two principle rules. The first one is preserving the same average value before and after data embedding. The second one is embedding the watermark bit, b, b ε (0, 1), by modifying the higher frequency coefficients or difference between two adjacent pixels (h).

The bit stream, B, which is the embedding payload in this method, consists of three parts: L, which is the compressed location map and shows the place of expandable difference, C, which is the compressed LSBs of the original image used to ensure exact reconstruction and P, which is the hash message of the original image. The expandable and changeable definitions as well as the complete procedure of difference expansion are given as follows:

In the DE method, firstly, a pair of pixels (x, y) is chosen and the following transformation is then performed on them [2, 26, 27]:

$$l = \left\lfloor \frac{x+y}{2} \right\rfloor , h = x - y \tag{1}$$

In this transformation, l is the average value, h is the difference value, x and y are integer values in the range of $0 \le (x, y) \le 255$. $\lfloor x \rfloor$ operation produces the greatest integers equal to or less than x. The inverse transformation is:

$$x = l + \left\lfloor \frac{h+1}{2} \right\rfloor , y = l - \left\lfloor \frac{h}{2} \right\rfloor \tag{2}$$

For preventing overflow or underflow during the embedding process, the pixel pairs are divided into two groups according to their h characteristics.

- **Changeability:** For gray pixels (x, y), difference value h is changeable if:

$$\left| \left\lfloor \frac{\mathrm{h}}{2} \right\rfloor \times 2 + \mathrm{b} \right| \le \min(2(255 - \mathrm{l}), 2\mathrm{l} + 1) \tag{3}$$

- **Expandability:** For gray pixels (x, y), difference value h is expandable if:

$$|2 \times \mathrm{h} + \mathrm{b}\,| \le min(2(255 - l), 2l + 1) \tag{4}$$

In the embedding procedure, the difference value h will be replaced by h'. The modification of h is according to the following equations:

$$h' = 2 \times \mathrm{h} + \mathrm{b} \qquad , \mathrm{b} = \mathrm{LSB}\,(h') \quad \textit{for expandable} \tag{5}$$

$$h' = \left\lfloor \frac{h}{2} \right\rfloor \times 2 + \mathrm{b} \qquad , \mathrm{b} = \mathrm{LSB}\,(h') \quad \textit{for changeable} \tag{6}$$

where b is one bit of the embedding payload B that can be 0 or 1 and h' is the difference expansion after embedding the watermark bit b. Finally, by using h', the new pixel values x' and y' are obtained through the following equations and this procedure is continued until all payloads B are embedded into the original image.

$$x' = l + \left\lfloor \frac{h'+1}{2} \right\rfloor , y' = l - \left\lfloor \frac{h'}{2} \right\rfloor \tag{7}$$

The LSB values for the expandable pixels do not need to be saved after embedding the watermark. Consequently, the amount of payload C will be reduced because it only includes the LSBs of changeable pixels. The extraction by difference expansion method is summarized in the following section.

To extract the watermark, the same procedure as in the embedding section should be followed. Firstly, a set of differences between neighbor pixels must be computed. Then the changeable and unchangeable difference numbers are separated and put in sets C and NC respectively. The bit stream B is created by taking all the LSBs of h, which belong to the set C (changeable h). The next steps are decompressing bit-stream B, separating the location map from B and recovering the original difference values (h) from the location map. By having the original difference values (h), the original image can be retrieved. The remaining part of B is an embedded payload and contains the hash message. By comparing this hash message and the hash of the restored image, it can be concluded that the content of image is authenticated if they match exactly.

3.0 HISTOGRAM MODIFICATION SCHEME

This method was proposed by Ni *et al*. [28] and takes the global characteristics of the original image into account for embedding watermarks. This scheme tries to shift the values between the minimum and maximum points of the histogram to perform data hiding [2]. Not only very little side information is generated by this method, but this method can also be implemented easily. However, the embedding capacity of this method is limited by the number of occurring maximum points.

The procedure for this method is described with a simple example in the following steps, but for more details of this method, the reader can refer to Ni *et al.* [28]. Consider the test image Lena with the size of 512×512. By depicting the histogram of this image, it can be seen that in the luminance value of ‘159’, the histogram has the maximum occurrence value of ‘2966’. By finding the pixels with a luminance value equal or larger than the peak point luminance and moving them to the right in the histogram, the luminance value ‘159’ will be blanked and the secret data can be embedded as follows [26].

Step1: Scan the whole image, pixel by pixel to find the pixels with luminance value ‘160’. The watermark bits are embedded by these rules:

a. If the watermark bit is ‘0’, the pixel with luminance value ‘160’ should be decreased to ‘159’.
b. If the watermark bit is ‘1’, the pixel with luminance value ‘160’ should be kept unchanged.

Step2: All pixels with other luminance values also should be kept unchanged.

For retrieving the embedded information at the decoder, follow these steps:

Step1: Before extracting the secret data, the peak point of the luminance value should be known and this data is called “side information”. This value in our example is ‘159’.

Step2: Start to scan the image pixel values of the watermarked image:

a. For pixels with luminance value equal to ‘159’, the extracted watermark is set to ‘0’ and luminance value is changed to ‘160’.
b. For pixels with luminance value equal to ‘160’, the extracted watermark is set to ‘1’ without changing the luminance value.
c. The pixels with other luminance values must be kept unchanged and no hidden data can be obtained

Step3: In image generated in step 2, by decreasing the pixels with a luminance value larger than ‘159’ by one unit, the original image can be retrieved in the decoder.

4.0 COMPARISONS BETWEEN DE AND HISTOGRAM MODIFICATION METHODS

In this section, the DE and histogram modification watermarking methods are compared together and the advantages and disadvantages of each are discussed.

4.1 Advantages Of The Histogram Modification Method

The histogram-based method preserves image quality and produces small amount of side information. This method generates 2 bytes of side information, which consist of the luminance value and the minimum and maximum points in the image histogram [2]. However, the DE method generates side information of differing lengths. One of them is the location map, which length directly depends on the cover image, and its size will vary from one image to another. The generated side information in the histogram-based method is very small in comparison to the DE method [26].

4.2 Disadvantages Of The Histogram Modification Method

The capacity of the histogram-based method might not be enough for embedding all the secret data bits because a number of max points limit the capacity of the method. It can be said that the main drawback of the histogram-based method is the limited amount of embedding capacity. For example the embedding capacity is equal to L/(M×N) bits per pixel (bpp), where L is the number of max point occurrence and M×N is the image size [26]. Due to simplicity of the histogram-based method, one desirable improvement can be a way to increase the embedding capacity of this method.

4.3 Advantages of The DE Method

Consider the Lena 512×512 used as the test image. Among the 1/2×512×512=131072 pairs of pixels for embedding data, 37343 bits are needed for embedding the location map, 6529 bits are needed for embedding the original LSBs of the changeable pixels pairs and expandable non-zero pixel pairs and 115 bits are needed for embedding the header information. The remaining bits are 131072-37343-6529-115=87085 bits. Thus the effective capacity in DE method for the mentioned test image is 87085 bits or 87085/(512×512)=0.33 bpp. In the same test image for the histogram-based method, the embedding capacity is 2966/(512×512)=0.0113 bpp. This means that the embedding capacity in DE method is 0.3322/0.0113=29 times more than the histogram-based method. Note that the capacity calculation of this part is according to our implementation with assistance from Huang and Chang [26].

4.4 Disadvantages of The DE Method

The main drawback of DE method is the generation of huge amounts of side information, which reduces the effective embedding capacity meaning that the quality of the watermarked image cannot be assured because by embedding more information, the quality will be degraded [26]. Furthermore, the DE method needs more calculations for obtaining the required side information compared to the histogram-based method.

The mentioned advantages and disadvantages of histogram modification and DE watermarking methods are summarized in Table 1.

Table 1 Comparison of the histogram modification and DE methods

	Methods	
Comparison Factor	Difference Expansion	Histogram Modification
Capacity	high	low
Side Information	bulky & variable	small & fixed
Complexity	high	low
Visual Quality	low	high

In order to compare the visual quality of the two explained methods, the watermarked version of Lena is illustrated after applying each of these methods (See Fig1). Furthermore, the Peak Signal to Noise Ratio (PSNR) versus the embedding capacity of these techniques is depicted in Fig 2.

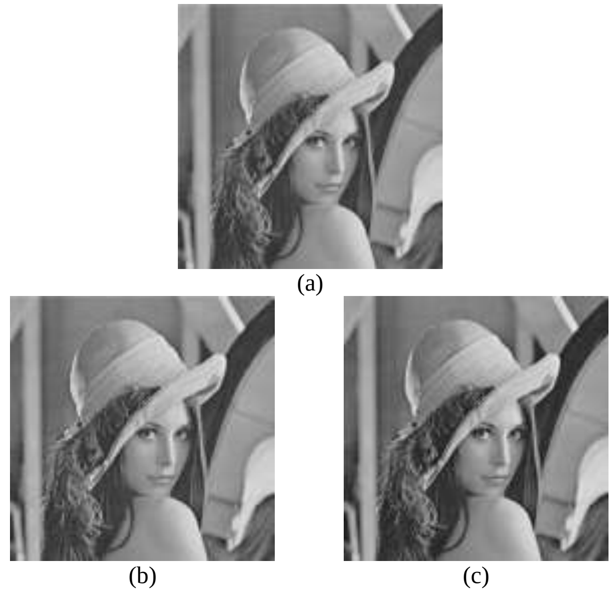


Figure 1 Simulation results for Lena: (a) Original image. (b) watermarked image by histogram modification method, PSNR = 32.392 dB after embedding 206641 bits (0.7883 bpp); (c) watermarked image by DE method PSNR = 32.54 dB after embedding 222042 bits (0.85 bpp)

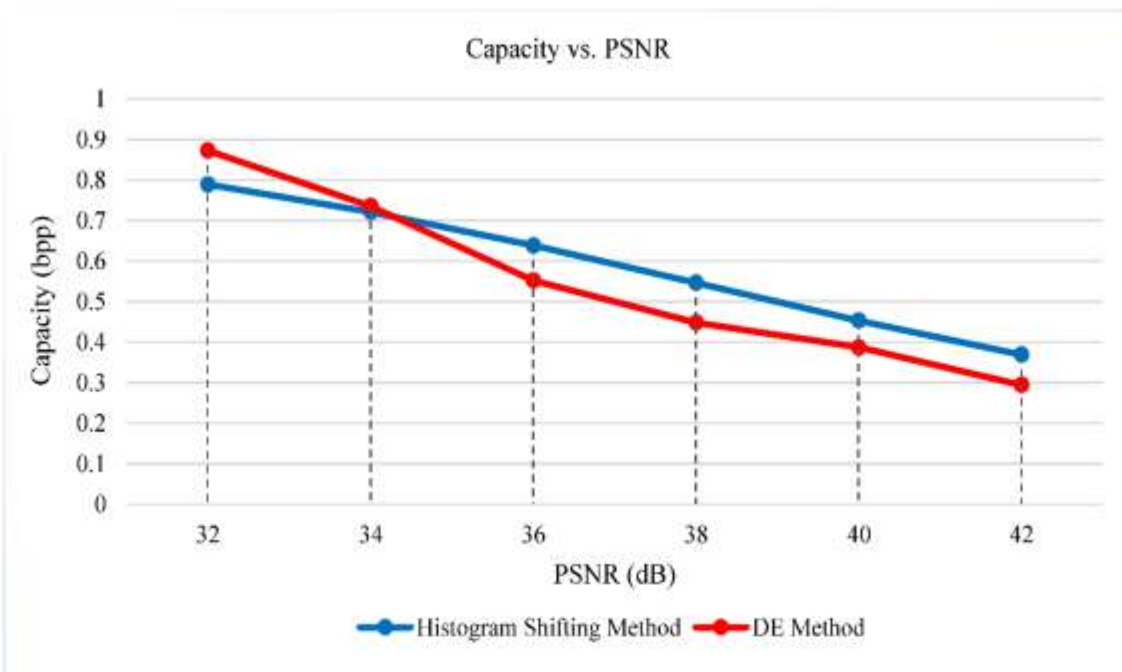


Figure 2 Performance comparisons after using DE and histogram shifting method on the Lena image

As mentioned before, the maximum capacity of the histogram shifting method is lower than the DE technique and this fact is demonstrated in Fig. 2. Furthermore, with equal capacity, the PSNR of the histogram shifting method is higher than the DE method; however, by increasing the embedded data the DE method shows better PSNR in comparison to the histogram shifting algorithm.

5.0 CONCLUSION

In this paper, we have studied reversible watermarking methods that are also known as lossless or reversible watermarking. As explained before, in reversible data hiding, not only the watermark, but also the original multimedia is restored perfectly, which is a critical requirement for medical and military applications. Afterwards, we have presented different classifications of reversible methods based on the previous literature. Among the numerous reversible watermarking methods available, the difference expansion and histogram shifting methods are two important algorithms that we have explained in this work. It has been shown that the embedding capacity of the histogram shifting method depends on the number of maximum points of the image histogram. Because the number of maximum points are limited, the histogram modification method has a lower embedding capacity in comparison to the DE method. In addition, the histogram shifting method generates a small amount of side information and the DE method generates a large amount of side information, the length of which depends on the image.

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