Recursive Reversible Image Watermarking Using Enhancement of Difference Expansion Techniques

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ABSTRACT: *This paper proposes a high capacity reversible image watermarking scheme based on enhancement of difference expansion method. Reversible watermarking enables the embedding of useful information in a host signal without any loss of host information. We propose an enhancement of Difference Expansion technique whereby we can embed recursively into multiple layer of payload for grey scale and also RGB color scale, hence it increase capacity much better. The proposed technique improves the distortion performance at low embedding capacities and mitigates the capacity control problem. We also propose a reversible data-embedding technique with blind detection of watermark. This new technique exploits the selection of optimum block size to implement the algorithm. The experimental results for many standard test images show that multilevel of embedding increase the capacity when compared to normal difference expansion. There is also a significant improvement in the quality (PSNR) of the watermarked image, especially at moderate embedding capacities.*

Keywords: Recursive, Multilayer embedding, Difference expansion, Blind detection, Reversible watermarking

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1. Introduction

Digital watermarking is a process of embedding valuable information into another digital media called host for the purpose such as copy control, authentication, copyright protection and distribution tracking. When inserting the watermark into the host, there are distortion occur and become constraint so that the host and the watermarked work are perceptually equivalent. Watermarking valuable and sensitive images such as medical, military and artwork images gives a big challenge to most watermarking methods. Watermarking process normally introduces small changes in host image but irreversible degradation in the original image. This degradation may cause the loss of significant artifacts in military, medical images and may reduce the aesthetic and monetary values of artwork.

Reversible watermarking is one type of fragile watermarking in which the watermark is sensitive to any intentional or unintentional forge of the watermark bit. Content authentication [24] is one of the applications using the fragile watermarking techniques. Reversible watermarking is one type of digital watermarking with an intriguing feature that when the watermarked bit has been authenticated, enables the decoder not only extract the watermark, but also perfectly reconstruct the original host to produce the exact original image, that is un-watermarked content [1]-[23]. This application of getting back the exact original content is highly important in sensitive imagery applications such artwork, law enforcement, medical imaging, astrophysics research, and military application. Having the original image during analysis and diagnosis to make the right decision is a very critical importance. Traditional watermarking techniques cannot provide adequate security and integrity for content authentication because of their irreversible nature.

Reversible watermarking, which is also called as erasable watermarking, invertible watermarking and lossless watermarking has been widely studied in the current literature of watermarking applications [1]-[14],[23].

There are several techniques introduced to solve reversible watermarking applications [1]-[22]. The first was introduced by Mintzer et al.[10] where the embedded watermarks were visible and could be extracted and removed because it was embedded in reversible approach. Fridrich et al. [7][8] compresses extracted vector which represents a group of pixels group, and embed payload by adding it to compress vector. Tian[4] method based on difference expansion with high capacity and quality. He applies a pair of pixels by determining their average and different of pixel values. The pixel value for selected pair of pixel will be updated during embedding process.

Alattar [2] introduced an algorithm with high capacity for color images. Payloads are hides in the difference expansion of vectors of adjacent pixels. Celik et al. used LSB-substitution technique and achieved high capacity by using a prediction based conditional entropy coder [3].

Reversible watermark techniques must have the ability to reconstruct the exact original host data after the extraction process. Therefore, the system should have three main steps. First embedding watermark bit w to digital host h, the result is h' = h + w. The second is digital content authentication by extracting the watermark signal from the watermarked image h'. If it is not tempered means authentic, we go to last step to reconstruct the original image y exactly as before the first step take in place.

In this paper we describe a high capacity, high quality reversible watermarking algorithm for digital image. Our method can be applied for both type of images, grey scale and also color image. Our process starts with scanning the embeddable pair of pixel which will not become overflow after embedding process. We sort by ascending order the selected pairs of pixel by using their difference values. This will make the pair of pixel which has the smallest different will be the first that will embed by the watermark bit. After embedding the watermark, only one pixel from a selected pair of pixel is changed it's value. We recursively embed the hidden data to the host image until the quality of image PSNR (peak signal to noise ratio) is become below 30[24], then we stop.

2. Enhancement of Difference Expansion (DE) Techniques

We use a modified version of Difference Expansion (DE) in [1-4]. We embed multilayer (*n* layers) of payloads into a host image *h*, and obtain *n* number of watermarked image *n* x *h*'. Before sending it to the content authenticator, the image *h*' might or might not have been tempered by some intentional or unintentional attack. If the authenticator finds that no tempering occurred in *h*', i.e. *h*' is authentic, then the authenticator can remove all the payloads *w* from *h'* to restore the original image, which is a new image *h*''.

Our approach of reversible watermarking is using enhancement of DE whereby first we select embedding pairs of pixel in a block and register their positions in a lookup table (*LT*). This *LT* is very important during embedding, extraction and restoring the original image. This DE technique removes the need of lossless compression on host image and also watermark image. This new enhancement DE allows the smooth areas to keep the one bit of payload. Smooth areas are the case where the difference value pair of pixel is zero or one.

Let we take pair of pixel (x_i, y_j) in an image $h, (x_i, y_j) \in Z$, where $0 \le (x_i, y_j) \le 255$, $1 \le i \le$ row and $1 \le j \le$ column. Define k = 1 to *p,* where *p* is total pair of pixel in *h*, d_k difference between kth pixel pair, and $y_i > x_j$ as follows;

$$d_k = y_j - x_j \tag{1}$$

Let *b* is a message bit either 0 or 1, d_k' is a new difference after adding with message bit,

$$d_k' = d_k + b \tag{2}$$

Now let y_j' new pixel value after add by d_k'

$$y_i' = y_i + d_k' \tag{3}$$

The new value for kth pair pixel is

$$(y_i', x_j)$$

The inverse transform of (3) is

$$y_i = y_i' - \left\lfloor \frac{(yi' - xj)}{2} \right\rfloor - b \tag{4}$$

Where is symbol $\lfloor . \rfloor$ is the floor function meaning the greatest integer less than or equal to. As pixel values are bounded within the range [0,255], we have the following conditions;

$$y_i \le \left\lfloor \frac{(x_j + 254)}{2} \right\rfloor \tag{5}$$

Thus to prevent the overflow the greater pixel value y_i after embedding must fulfill condition (5). In our approach because pixel x_j is unchanged, underflow situation is not arise. The next step is to create lookup table for all expanded pair of pixels. We assign 1 to represent an expanded pair of pixels and 0 for the non expanded pair of pixel. Let *hs* is the size of host image *h,* and the size of lookup table *LT* in bit is given by

$$LT = 16n + n \times \tfrac{hs}{16} \tag{6}$$

The side information inside the *LT* is number of layers given by *n*, size of watermark for *n* layers and status of embeddable in every pair of pixels. In our approach we let the number of layers increase until PSNR value is below 30 [24].

3. Multiple layer of Reversible Watermarking Scheme

We describe our scheme by using flowchart and procedures as mentioned below.

3.1 Principle

The principle of this scheme consists of three modules; scanning, embedding and reconstruction. Figure 1 describes about scanning and embedding modules and Figure 2 illustrates about extracting and reconstruction module.

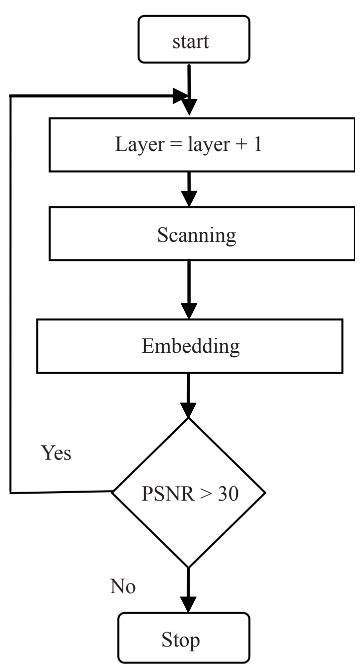

Figure 1. Reversible Watermarking Scheme: Scanning and Embedding

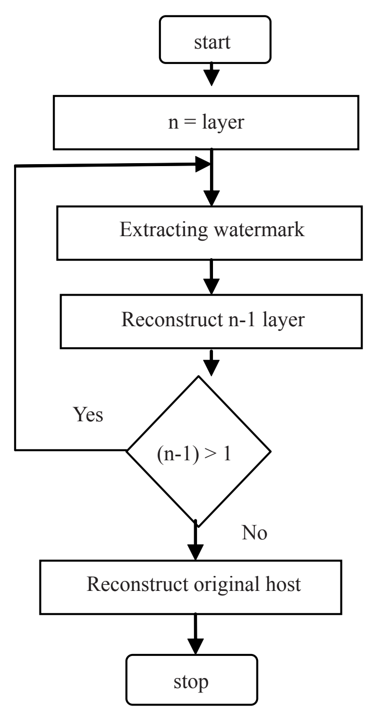

Figure 2. Reversible Watermarking Scheme: Extracting and Reconstructing

3.2 Lookup Table

The lookup table *LT* is a binary bitmap that indicates three things;

1. Size watermark image in each layer,
2. Numbers of embeddable layer in watermarked image,
3. Status pair of pixel either 0 for non selected pair or 1 for selected pair.

Lookup Table is a key required by decoder to retrieve the payload starting from last layer and to rebuild the original image after the first layer extracted. Since one bit is assigned to each pair, and for image with 8 bit per pixel, therefore for n layer of watermark, *LT* with size S is given by;

$$s = 16n + n \times \frac{hs}{16}$$

Let see this simple example of pixel of (2x4) image

$$\begin{bmatrix} a\,b\,c\,d \\ e\,f\,\,g\,h \end{bmatrix}$$

We trace the pair of pixels for the first layer by vertical approach starting from first pixel to last pixel according to the sequence of; a-e, b-f, c-g d-h. For second layer we reverse the process by horizontal tracing starting from last pixel going up to first pixel by combination of; h-g, f-e, d-c, b-a. The process of tracing continues by repeating the same process as above. This approach is taken because we want to obtain different value pair of pixel hence increase embeddable pair of pixel.

3.3 Scanning and Embedding

The detail procedure to identify embeddable pair is described below. Let us take pair of pixel (x_i, y_j) in an image h,$(x_i,y_j) \in Z$, where $0 \le (x_i, y_j) \le 255$, $1 \le i \le$ row and $1 \le j \le$ column. Here S_{ij} denotes the block in the i^{th} row and the j^{th} column.

The scanning process involves the following steps:

1. Partition the entire image *h* into similar block size with pairs of pixels S_{ij};

2. Determine status of every pixel pair either overflow or not by using equation (5).

3. Set 1 for embeddable pair and 0 for un-embeddable pair in look-up table.

4. End.

The embedding step continues after the above process complete;

1. Read look-up table and host image *h*

2. Sort S_{ij}; according to d_k

3. For all block S_{ij};

4. If (x_i, y_j) is embeddable,
   Execute equations (1),(2),(3)
   end if
   end for

5. End.

The recursive step is a process of iterating the process of scanning and embedding until the PSNR value is less than 30. We can embed *n* watermarks images if we have *n* layers of embedding.

3.4 Extraction and Recovery

Extraction is conducted for the purpose of authentication where in the first process; hidden payload is extracted from watermarked image starting from last layer. The second process is original image is constructed from watermarked image after we reach top of layer.

Process involves are;

1. Read *LT* and host image *h*
2. Read max layer *n* from *LT*
3. For all block S_{ij};
4. If (x_i, y_j) is embeddable
   Determine hidden bit *b*
   Execute equations (4)
   end if
   end for

1. n=n-1
2. if n > 1
   go to step 3.
   end if
3. construct *h*

   end.

4. Experimental Results and Comparisons

We discuss the result, analysis and compare our result with another algorithm in DE.

4.1 Experimental Results

We implemented and tested the algorithm given in 3.3 and 3.4. For different types of images we implement the algorithm and calculate payload, bit rate and PSNR. We apply the algorithm recursively for 20 different types of RGB and gray scale images. In Table 1 to 3 below, we present our result based on three images. Maximum layer we set is 8, because size of lookup table will increase as value of number of layers increase. During embedding phase we list out for each layers; name of images, payload, bit rate for each layer, total bit rate and PSNR value. For first layer we embed the payload is text file and the following layers are images.

4.2 Analysis

It clearly shows that for the first layer PSNR value is very high. This is because the payload size is less than the total case for d_k is equal zero or one. The table indicates that the achievable embedding capacity depends on the nature of the image itself. Some images can accept more payload bits with lower distortion in the term of PSNR compared to other images. For example Lena and Car produce more expandable pairs with lower distortion compared to image with more edge areas such as baboon, and hence the former images can carry more watermark bit at higher PSNR.

Image: Lena.jpg		Host size : 262144 byte	
layer	Payload(bit)	Total bit rate	PSNR
1	1519	0.006	73.52
2	8000	0.036	63.33
3	30360	0.152	51.40
4	80000	0.457	41.20
5	30360	0.573	39.91
6	96000	0.939	32.43
7	30360	1.06	31.95

Table 1. Image Lena.jpg

Image: baboon.jpg		Host size : 65536 byte	
layer	Payload(bit)	Total bit rate	PSNR
1	1519	0.023	61.19
2	8000	0.145	44.25
3	8000	0.267	40.43
4	8000	0.389	35.94
5	8000	0.512	33.48
6	8000	0.634	31.02

Table 2. Image baboon.jpg

Image: car.bmp		Host size : 562500 byte	
layer	Payload(bit)	Total bit rate	PSNR
1	1540	0.003	76.80
2	8000	0.017	66.64
3	8000	0.031	63.85
4	96000	0.202	47.65
5	102400	0.384	39.91
6	80000	0.526	35.52
7	96800	0.698	31.65

Table 3. car.bmp

4.3 Comparisons with Other Algorithms

Figure 3 below is a comparison between Tian's [4] and Lee's [20] algorithm and our propose algorithm upon the value of bit rate (bpp) and PSNR (dB) using image "Lena" (512 by 512)

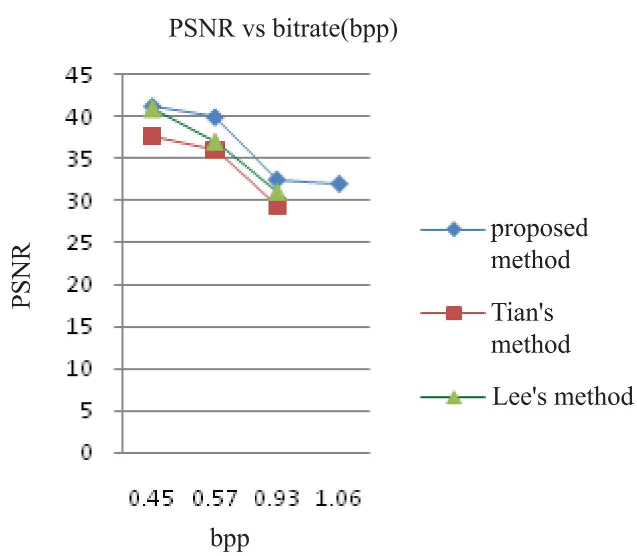

Figure 3. PSNR for Tian's, Lee's and proposed method with respect to bit rate(bpp) on 'Lena'

Tian's and Lee's technique performs in term of PSNR almost similar results when bit rate is 0.45. For higher payload, our propose technique outperform other technique whereby the bit rate is greater than one.

5. Conclusion

In this paper, a very high-capacity algorithm based on the difference expansion of multilayer of embedding for reversible watermarking with low image distortion is implemented. Test results show that the amount of data, one can embed into an image depends highly on the nature of the image. The test results also indicate that the performance of the propose algorithm is superior for images with smooth area.

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