Reversible Image Data Hiding with Local Adaptive Contrast Enhancement

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Abstract Recently, a novel reversible data hiding scheme is proposed for contrast enhancement by Wu (IEEE Signal Process Lett 22.1:81–85, 2015). Instead of pursuing the traditional high PSNR value, he designs the message embedding algorithm to enhance the contrast of the host image. In this paper, an extended scheme is proposed to not only adaptively enhance the contrast of the image, but also to keep the PSNR value high meanwhile. Firstly, the original host image is divided into non-overlapping blocks, such that the local contrast of the image can be enhanced adaptively. Secondly, we classify the pixels of each block into two sets, the "referenced" set and the "embedded" set, and then processing them alternatively such that additional side information is eliminated. Experimental results demonstrate that our proposed algorithm achieves increased local visual quality and performs better than Wu et al.'s scheme with keeping image's PSNR high as criterion for RDH.

Keywords Local adaptive · Contrast enhancement · Histogram modification · Reversible data hiding

1 Introduction

Data hiding is applied extensively in the community of signal processing, such as ownership protection, fingerprinting, authentication and secret communication. The most classical data hiding technique leads to permanent distortions. In last decades, reversible data hiding (RDH) [1–11] as a new type of information hiding technique, has received much attention. RDH provides not only extracting embedded data precisely, but also restoring the original cover image without any error. This special

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property has been found much useful in many sensitive fields, such as medical imagery, military imagery and law forensics, where any change on the host signal is not allowed.

The classic RDH algorithms mainly adopt three techniques, histogram shifting (HS) [3], difference expansion (DE) [4] and prediction-error expansion (PEE) [5]. There are two important metrics to evaluate the performance of a RDH algorithm: the embedding capacity and the distortion. In fact, we always keep the balance between this two metrics, because a higher embedding capacity often cause more distortion and decrease the distortion will result in a lower embedding capacity, so we usually use the Peak-Signal-to-Noise-Ratio (PSNR) to evaluate the performance of algorithm.

Recently, Wu et al. proposed a new RDH algorithm with contrast enhancement [1]. They deemed that the improvement of visual quality is more important than keeping the image's PSNR high. By using some pairs of peaks, the histogram of pixels values is modified to achieve histogram equalization, thus leading to the image contrast enhancement while RDH is realized. The method provides a new direction for the research of RDH.

Contrast enhancement is a meaningful application by RDH, but in real life, local adaptive contrast enhancement is more widely used, such as military images, medical images, etc. In this paper, we considerably extended Wu et al.'s method in order to have a better performance. Firstly, we proposed to cut the original image into several blocks, by manipulating the more centrally distributed block histogram, local adaptive contrast enhanced effect can be achieved. Meanwhile however, if we do the same histogram shifting operation as Wu et al.'s method, we need 16 excluded pixels to record the side information for extracting embedded information and recovering image completely for each individual block, which will loss pure payloads for data embedding. Considering this limitation, the other improved method, double-layered histogram shifting, designed. We divide the pixels of each block into two sets, the referenced set and the embedded set, because the histogram of this two sets are similar, we can shift histogram of the embedded set according to the bins of the referenced set, and then operate histogram of the referenced set based on the bins of the modified embedded set. Since the histogram of the referenced set keeps no changed when embedding the message bits into the embedded set, we do not need 16 pixels to record the value of last two peaks. The experimental results demonstrate that our proposed method achieves increased local visual quality and performs better than Wu et al.'s scheme with keeping image's PSNR high as criterion for RDH.

The rest of the paper is organized as follows: Sect. 2 discusses the important issues regarding Wu et al.'s method, and Sect. 3 describes the detail about our proposed RDH algorithm featured by adaptive local contrast enhancement. The experimental results compared to the previous method demonstrated in Sect. 4. Finally, a conclusion is drawn in Sect. 5.

2 RDH Algorithm with Contrast Enhancement

In Wu et al.'s paper, they tend to enhance the contrast of a host image to improve its visual quality instead of trying to keep the PSNR high, and at the process of embedding data, the side information is embedded into the host image along with the message so that the original image can be recovered completely. Before manipulating the pixel histogram, a pre-processing is used to prevent the overflow and underflow. For a given 8-bit gray-level image I, supposing that the amount of peak-pairs to be spilt is L, excluding the first 16 pixels in the bottom row, all pixels values from 0 to L-1 are added by L. Also, the pixels value from 256-L to 255 are subtracted by L. The position information of modified pixels in the operation has been record in a location map. And then, the image histogram can be calculated by counting the pixels, h(i) represents the numbers of pixels with gray level value i. Based on image histogram, we choose the highest two bins and the corresponding smaller and bigger values are denoted by I_S and I_R, respectively. Then the bins with value between this two peaks keep unchanged while the outer ones are shifted outward so that I_S and I_R can be spilt into two adjacent bins for information embedding. The data embedding process performs by:

$$i' = \begin{cases} i-1, & \text{for} \quad i < I_S \\ I_S - b_k, & \text{for} \quad i = I_S \\ i, & \text{for} \quad I_S < i < I_R \\ I_R + b_k, & \text{for} \quad i = I_R \\ i+1, & \text{for} \quad i > I_R \end{cases} \tag{1}$$

where i' is the modified pixel-value, and b_k is the k-th message bit (0 or 1) to be hidden. We can embed the amount of (h(I_S) + h(I_R)) bits into the image by Eq. (1). To increase the embedding capacity, same process repeat by selecting more peak-pairs in the modified histogram until meeting the requirement. The compressed location map is embedded into the image before message bits to be hidden, the side information including the value of L, the size of the compressed location map, the least significant bits (LSBs) and the previous peak values is embed using the last two peaks to be spilt. At last, the LSBs of the 16 excluded pixels in the bottom row are replaced by the value of the last two peaks. With this embedding process, histogram equalization achieved, which leads to contrast enhancement.

$$b'_k = \begin{cases} 1, & \text{if} \quad i' < Is - 1 \\ 0, & \text{if} \quad i' = Is \\ 0, & \text{if} \quad i' = I_R \\ 1, & \text{if} \quad i' = I_R + 1 \end{cases} \tag{2}$$

The extraction and recovery process as follows:

(1) By retrieving the LSBs of the 16 excluded pixels in the bottom row, we get the values of the last two spilt peaks.

(2) The value of L, the length of the compressed location map, the original LSBs of 16 excluded pixels, and the previously spilt peak values are extracted by using Eq. (2).
(3) The recovery operations are carried out by processing all the pixels except the 16 excluded ones with Eq. (3) from previous spilt and then repeated until all of the spilt peaks are restored and the data embedded with them are extracted.
(4) Knowing the length of the compressed location map, the compressed location map obtained from the extracted binary values decompress to the original size.
(5) From the location map, those pixels modified in preprocess are identified, and pixel value is subtracted by L if it is less than 128, or increased by L otherwise.

$$i = \begin{cases} i' + 1, & \text{for} \quad i' < Is - 1 \\ Is, & \text{for} \quad i' = Is - 1 \text{ or } i' = Is \\ I_R, & \text{for} \quad i' = I_R \text{ or } i' = I_R + 1 \\ i - 1, & \text{for} \quad i' > I_R + 1 \end{cases} \tag{3}$$

3 Our Proposed RDH Algorithm

3.1 Adaptive Block Division

Compared to Wu et al.'s algorithm, we adopted two improved method to achieve better performance. First, we cut the original image into several blocks, usually the size of block is 16 × 16 or 32 × 32, and then operate each individual block histogram using Wu et al.'s method, as result, local adaptive contrast-enhanced effect can be realized. For each individual block, the gray level of pixels relatively will be more close to, that is, the histogram will be steeper than that of the original image, in this way, the embedding capacity can be increased in a big range.

3.2 Double Layered Embedding

If using Wu et al.'s method for information embedding after blocking, we need to exclude 16 pixels to record the last two peaks for each individual block, which will loss pure payload for data embedding. At the same time, we find that, if we divide the pixels in a block into two sets, the pixel histogram of them are very similar, as shown in Fig. 1.

Considering this two aspects, we design the other improved method: double-layered embedding. We use Fig. 2 to example the process of double-layered embedding operation:

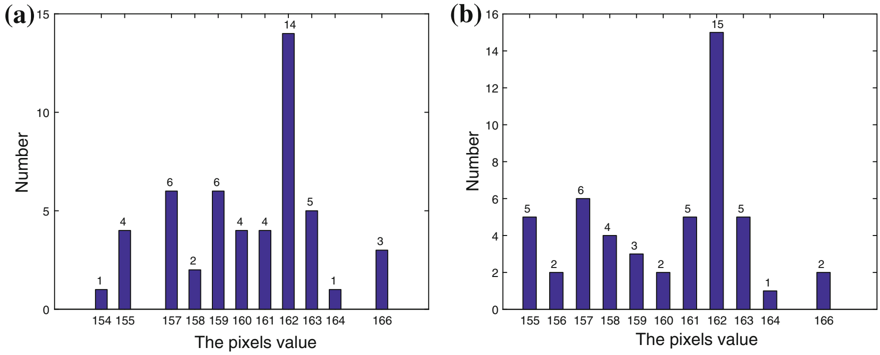

Fig. 1 Histogram of the reference set and the embedded set for one block of "Lena"

(1) Given the original image divides into several 10 × 10 blocks by adaptive block division operation, and then we divide all the pixels in a block into the referenced set (Fig. 1a) and the embedded set (Fig. 1b);
(2) Based on the histogram of referenced set, we pick out the highest two peaks and then operate the histogram of the embedded set using Wu et al.'s method as IS and IR are the pixels whose value equal to the two peaks on the referenced set, the histogram of embedded set (Fig. 1b) changes to (Fig. 2a);
(3) Selecting the highest two peaks on the modified histogram of embedded set, then operating the histogram of referenced set using Wu et al.'s method as I_S and I_R, are the pixels with the same value of the two adopted peaks, in this way, the histogram of referenced set (Fig. 1a) changes to (Fig. 2b);
(4) Utilizing the same process for all the blocks and repeating several rounds until finish embedding the bits stream, which includes compressed location map and messages to be hidden;
(5) The side information including the value of L rounds and the length of compressed location map embed at the last round.

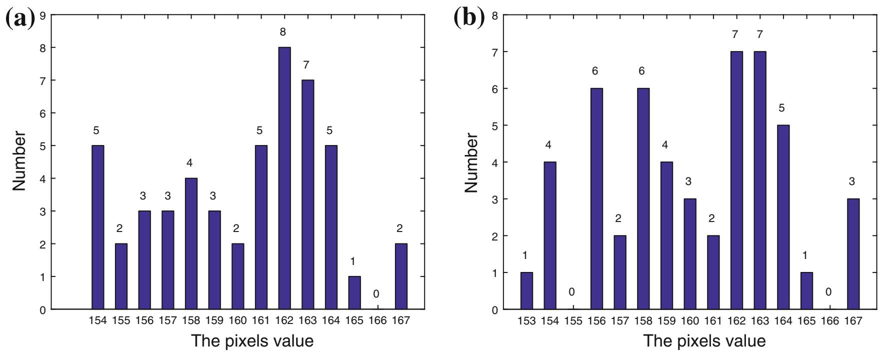

Fig. 2 The modified histogram of the reference set and the embedded set for one block of "Lena"

The extract and recovery process are as follows:

(1) According to the protocol sender and receiver set, the size of block and the last set for information embedding can be obtain, usually the size of block is 16×16 or 32×32.
(2) The length of compressed location map and the value of L can be get by extracting the last two peaks.
(3) The information embedded and the compressed location map are extracted by using Wu et al.'s method.
(4) The location map can be get.
(5) Original image is recovery completely.

4 Experimental Results

Our proposed method compared to the method of Wu et al., using typical 512×512 grayscale images (i.e. Lena, Tank, Barbara) with the experimental environment of MATLAB R2014 under windows 7. For all images, the performance of our proposed method is better.

Besides our block and dividing algorithm, the embedding method in these two algorithms keeps the same thing. As shown in Table 1, for these two algorithm, the payload are both increased by using more peak-pairs for data embedding, that is, increasing the parameter L; and because our proposed algorithm manipulate more centrally contribute histogram in each individual block, the pure hiding rate (Payload) is better than Wu et al.'s method in a big range. What's more, from the PSNR-to-Payload curve in Fig. 3, we also can get a conclusion that our method can embed more data when leads to the same distortion, and if we embed the same amount of data, the host image can be modified less, which means that our embedding performance is superior to Wu et al.'s method.

We select several grayscale images to compare the contrast-enhanced visual quality, due to space limitation, only the result of image "kidney" shown in this paper. The marked image in Wu et al.'s method and in our proposed method shown in Fig. 4, respectively. From (c) and (d) in Fig. 4, local adaptive contrast-enhanced visual quality is observed, obviously.

Table 1 Comparing the PSNR and payload for different pairs of histogram peaks of this two method

Lena	Wu et al.'s algorithm		Our proposed algorithm	
	PSNR (dB)	Payload (bpp)	PSNR (dB)	Payload (bpp)
L = 2	42.1844	0.0309	43.0228	0.2066
L = 4	36.7746	0.0694	37.0637	0.2999
L = 6	33.2580	0.1061	33.5421	0.3627

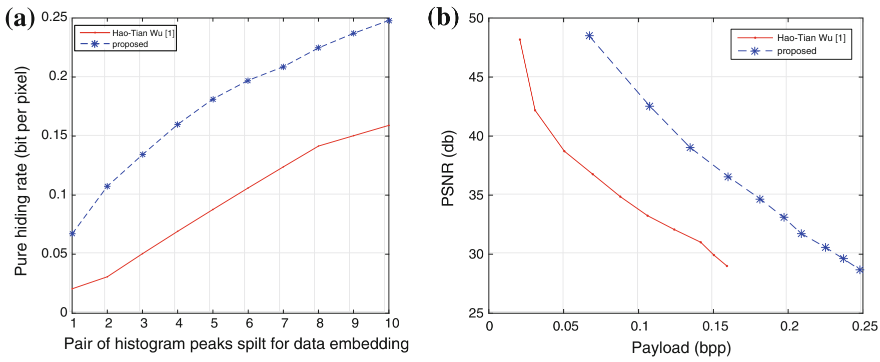

Fig. 3 Comparison about two methods for image "Lena"

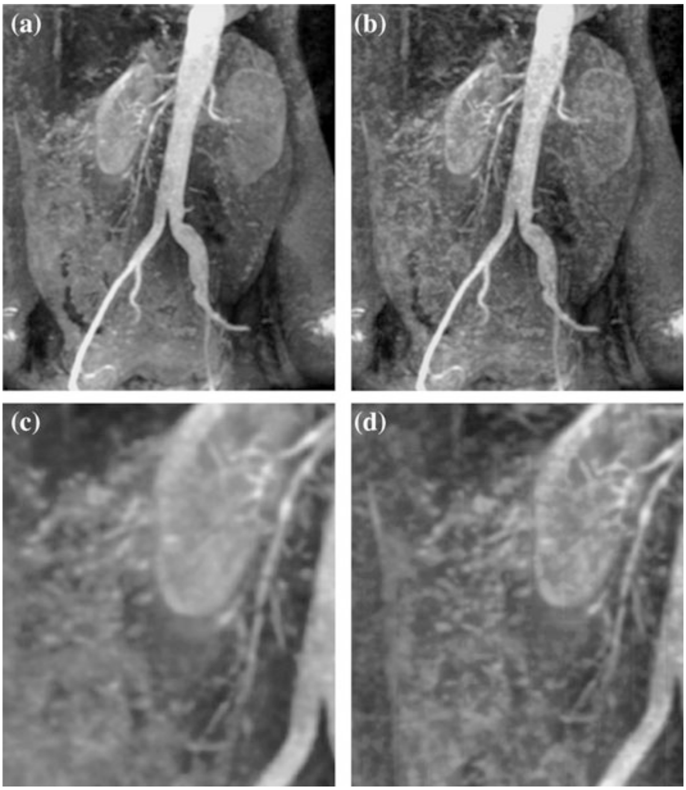

Fig. 4 **a** The marked image in Wu et al.'s method **b** The marked image in proposed method **c** local detail in Wu et al.'s method **d** local detail in proposed method

5 Conlusion

In this paper, based on a new reversible data hiding algorithm of Hao-Tian Wu, with the property of contrast enhancement, an improved method has been proposed. Dividing the original image into several blocks, the local adaptive contrast enhancement realized, in this way we achieve the contrast-enhanced effect on local sensitive region. After using a classic block method, we manipulate the more centrally distribute histogram, by which the experimental results produces more excellent ration between embedding capacity and distortion than the previous scheme. What's more, the smart operation of division for the histogram shifting method in our proposed algorithm significantly decreases the space for recording side information and may indeed eliminate the need for it sometimes, which is good for embedding capacity. Experimental results show that our proposed algorithm has better performance on local visual quality, embedding capacity and hiding distortion, compared to the algorithm of Hao-Tian Wu.

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