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A reversible data hiding method with contrast enhancement for medical images ☆

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ABSTRACT

In this paper, a reversible data hiding method with contrast enhancement is presented for medical images. Firstly, image background segmentation is performed and the principal gray-scale values in the segmented background are identified. By excluding the corresponding histogram bins from being expanded for data hiding, the contrast of region of interest (ROI) in medical images can be selectively enhanced. Considering the characteristics of pixel distribution, we develop a new pre-processing strategy to reduce the visual distortions that may be caused. With the proposed method, an original image can be exactly recovered from the corresponding enhanced image by hiding the side information within it. The experimental results on a set of medical images show that the visibility of ROI can be improved. Compared with the previous method, the proposed method can achieve more contrast enhancement effects and better visual quality for medical images.

1. Introduction

The developments in multimedia and digital communication technologies have provided more and more services, such as E-learning, web conference and digital diagnosis. On the other hand, digital content can be easily manipulated so that the integrity of data often needs to be authenticated. Over the past decades, reversible data hiding (RDH) has been extensively studied to embed a string of message bits (such as a digital signature) into a digital object (e.g. image, audio or video signal) so as to generate a marked object, from which the original object can be exactly recovered. Also referred as lossless data hiding, RDH is useful in the medical and military applications where no permanent change is permitted. Specifically, RDH can be used to hide authentication information into the marked object and retrieve the data when needed. In addition to authentication, the data hidden in a medical image may include Electronic Patient Records (EPR), which consists of diagnostic reports, vital signals and other information such as IDs [1]. Hence, RDH on medical images has promising applications and attracts interest in the community [2].

In the literature, a lot of RDH algorithms (e.g. [3–19]) have been proposed. Among them, most are for digital images in the plain text domain (e.g. [3–14]), and even in the encrypted domain (e.g. [15–18]). In the evaluation of image RDH algorithms, information hiding rate and quality of the marked image are two important metrics. To measure the distortion caused by data hiding, the peak signal-to-noise ratio (PSNR) between the original and marked images is often calculated. In the early RDH methods such as difference expansion [3] or histogram modification [4], relatively low hiding capacity is achieved by directly modifying the pixel values. In the recently proposed RDH algorithms (e.g. [6,12]), the prediction errors are generated from a pixel and its neighboring pixels to exploit the correlation between them. In this kind of RDH method, the pixel values are modified to manipulate the more centrally distributed prediction errors so that the PSNR value of the marked image can be kept high.

For the images with low contrast or poor visual quality, keeping the PSNR value high after RDH is not enough. Due to poor illumination in some imaging systems, the contrast of the obtained images is far from ideal. The perceptual quality of these images often needs to be improved by contrast enhancement, to increase the dynamic range or to bring out image details. For instance, it is often demanded that the contrast of medical or satellite images be enhanced to show the region of interest (ROI) for inspection. Contrast enhancement has been an active research topic for more

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than half a century. An early automatic procedure is histogram equalization [20], but a conventional equalization method is less effective when the contrast characteristics are different across the image. Recently, adaptive contrast enhancement methods have been developed by considering the local information (e.g. to generate the mapping for each pixel with a local histogram [21]). Since the existing contrast enhancement methods are all irreversible, the images will be permanently changed after being enhanced. So the original image needs to be properly kept to avoid information loss caused by contrast enhancement. Under the circumstances, it is advantageous to perform the RDH task with the additional functionality of contrast enhancement. If the obtained image is not suitable for a specific application and the original image is needed, it can be exactly recovered and then be processed again. So in [14], a RDH method is proposed to enhance image contrast instead of simply keeping PSNR high. By hiding the side information into the contrast-enhanced image, both data extraction and image recovery can be blindly performed.

Although reversible data hiding and image contrast enhancement are achieved in [14], the method has the following limitations: Firstly, the method is not specially developed for medical images but for natural images. It has been demonstrated by the experimental results that directly applying the method to medical images cannot achieve the satisfactory effects. Secondly, pre-processing is performed in [14] to avoid overflow or underflow of pixel values but artificial distortions are introduced, especially when a large number of histogram bins are expanded for data hiding (to be explained in the following section). To overcome the aforementioned drawbacks, a new RDH method is presented in this paper to reversibly enhance the contrast of medical images. Since most of medical images contain ROI and background (non-ROI) areas, background segmentation is carried out so as to selectively enhance the contrast of ROI. In practice, Otsu's method [22] is adopted to automatically segment an image into foreground (i.e., ROI) and background. Then the principal gray-scale values in the segmented background are identified and the corresponding histogram bins are excluded from being expanded for data hiding. Considering the characteristics of pixel value distribution in medical images, we design a new pre-processing strategy to reduce the visual distortions that may be caused. Two histogram intervals containing the minimum pixels are chosen instead of the ones used in [14]. Therefore, better visual quality of the enhanced images can be achieved with the proposed method.

The proposed RDH method is implemented on a set of medical images. The experimental results show that the visibility of ROI can be improved besides hiding the authentication information into the contrast-enhanced images. Moreover, the original medical images can be exactly recovered from the contrast-enhanced ones. The rest of this paper is organized as follows: In the next section, an overview of the proposed method is firstly given, followed by the detailed steps and implementation details. The experimental results of the new method are given in Section 3, and compared with the method in [14]. Finally, we summarize the paper and draw the conclusion in Section 4.

2. Proposed reversible data hiding method for medical images

The proposed reversible data hiding method consists of two processes: data hiding process, extraction and recovery process. By the end of data hiding process, a contrast-enhanced image is generated after performing data hiding and contrast enhancement on the original medical image. In the second process, the hidden data are extracted from the contrast-enhanced image and the original image is recovered accordingly. In the following, every step in the two processes will be introduced.

2.1. Process of data hiding

As shown in Fig. 1, there are three major steps in the data hiding process, i.e., background segmentation, pre-processing, and data embedding.

(1) **Background segmentation**: As mentioned, most of medical images contain region of interest (ROI) and background (non-ROI) areas, such as the three Computed Tomography (CT) images shown in Fig. 2. Although those medical images have quite different contents, a proportion of them are with the same or close values and make up background, respectively. Since it is useless or even unfavored to enhance the contrast of non-ROI, we perform background segmentation in the proposed method. In practice, Otsu's method [22] is adopted to automatically select the optimal threshold separating two classes of foreground pixels and background pixels. Due to the limit of space, we will not give the detailed implementation, which can be found in [23]. To exclude the background from contrast enhancement, one way is to process the segmented foreground only, but it is required that the same segmentation can be performed on the enhanced image to recover the original image. Since the original image will be changed after pre-processing and data embedding, there is no guarantee that the same automatic segmentation can be repeated on the enhanced image. An alternative way is to identify those gray-scale values in the segmented background whose percentages above a pre-defined threshold (e.g. 2%) and exclude the corresponding histogram bins from being expanded. The detailed operations will be described in the step of data embedding.

(2) **Pre-processing**: Before discussing this step, we briefly introduce the method in [14]: To perform contrast enhancement and reversible data hiding simultaneously, the histogram of pixel values is firstly calculated in [14]. Then the two peaks (i.e. the highest two bins, denoted by f_L and f_R) in the histogram are chosen at each time. By keeping the bins between the peaks unchanged and shifting the outer bins outward, each of the chosen peaks is expanded into two adjacent bins. That is, for a pixel with value f counted in the histogram, the following operation is performed

$$f' = \begin{cases} f-1, & \text{if } f < f_L \\ f-b, & \text{if } f = f_L \\ f, & \text{if } f_L < f < f_R \\ f+b, & \text{if } f = f_R \\ f+1, & \text{if } f > f_R \end{cases}, \quad (1)$$

where f' is the value generated to replace f, b is a binary value (0 or 1) to be embedded. The highest two bins in the modified histogram can be further chosen to be expanded, and so on until satisfactory contrast enhancement effect is achieved. To avoid the overflows and underflows due to histogram modification, the bounding pixel values are pre-processed. Suppose that S pairs of histogram peaks are expanded in total. In pre-processing, the range of pixel values from 0 to $S-1$ are added by S, while the pixels from $256-S$ to 255 are subtracted by S. To memorize the locations, a binary location map with the same size of image is generated by assigning 1s to the modified pixels, and 0s to the others. For the recovery of the original image, the location map is embedded along with the message bits and other side information in the marked image.

However, visual distortions may be introduced after pre-processing because a pixel previously with value $S-1$ will be brighter than a pixel with value S, which is called *disordering* of pixel values. Similarly, a pixel originally with value $256-S$ will be darker than another one with value $255-S$. For most of natural images, the number of bounding pixels (i.e. from 0 to $S-1$, and from $256-S$ to 255) are relatively small so that few visual distortions are introduced. But for most of medical images, obvious