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Reversible data hiding in medical images with enhanced contrast in texture area ☆

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ABSTRACT

In order to realize the patient privacy protection in medical image, opposite to traditional reversible data hiding (RDH) methods which prior to embed message into the smooth area for pursuing high PSNR value, the proposed method priors to embed message into the texture area of the medical images for improving the quality of the details information and helping accurate diagnosis. Furthermore, in order to decrease the embedding distortion while enhancing the contrast of the texture area, this paper also proposes a message sparse representation method. Experiments implemented on medical images showed that the proposed method enhances the contrast of texture area when compared with previous methods.

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1. Introduction

Reversible data hiding (RDH) is one kind of information hiding techniques with the characteristics such that not only the secret message needs to be precisely extracted, but also the cover image itself should be restored lossless [1–5]. This reversibility is important in some special scenarios such as medical imagery [6,7], military imagery and law forensics. In these applications, the cover is too precious or too important to be damaged.

Most of the state-of-the-art RDH methods are aim to providing a good performance in higher data embedding capacity and lower the distortion of the marked image [8]. Based on this purpose, many RDH methods on images have been proposed. All these methods are realized through a process of semantic lossless compression [1,9], in which some space is saved for embedding extra data by lossless compressing the image. This compressed image should be "close" to the original image, so one can get a marked image with good visual quality. The residual part of images, e.g., the prediction errors (PE), has small entropy and thus can be easily compressed. Therefore, almost all recent RDH methods first generate PEs as the host sequence [10–15], and then reversibly embed the message into the host sequence by modifying its histogram with methods like histogram shifting (HS) [16,17] or difference expansion (DE) [18]. Usually the prediction errors histogram (PEH) has a sharp distribution centered at zero. Another typical technique to get a good host sequence for RDH is sorting [11,19,20] or pixel selection [15], which gives priority of modifications to PEs in smooth regions. Because the pixels in smooth areas can be accurately predicted, so a sharper histogram can be obtained in such areas. In a word, the existing RDH methods used two techniques for pursuing high PSNR value, one is give priority of modifications to PEs in smooth regions, the other one is sort pixels based on smooth degree.

In most literatures on RDH, the quality of the marked image is assessed by peak signal-to-noise ratio (PSNR), with which a modification in smooth region is equally risk as a modification in noisy region. Hence, most state-of-the-art RDH schemes prefer to embed data into smooth area, which corresponded to middle region of PEH for pursuing high PSNR value. However, PSNR only depends on the quadratic sum of difference between original image and distortion image and had proved inconsistent with human visual perception in image quality assessment research [21]. Recently, instead of pursuing high PSNR value, Wu et al. [22] and Gao et al. [23] proposed reversible image data hiding with contrast enhancement, they all improved image visual quality through enhancing contrast of cover image. Wu et al.'s method applied HS scheme to select two highest bins of image histogram for data hiding and repeated this process until embedded all secret data, which in essence is a histogram equalization scheme for contrast enhancement. However, it enhances contrast in the global spatial domain but cannot restore the details of the image. In some applications,

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we need enhance the contrast of local area, such as in medical image enhancement. Gao et al.'s method embedded the data into spatial domain and IWT domain respectively, in which embedding procedure in spatial domain is same with Wu et al.'s method by adding the controlled threshold denoted by $T_{rce} = 0.55$ and then embedded the other data into the detail subbands. However, due to the most of medical images includes a lot of smooth area, so the results in Gao et al.'s method are same as Wu et al.'s method for T_{rce} less than 0.55.

In addition, in order to avoid hackers or attackers duplicated or revised medical information through the internet and to keep the medical image quality for accurate diagnosis, reversible data hiding plays an important role in medical images. As lot literatures shown, most of the RDH in medical images are all aim to achieving high capacity and pursuing high PSNR value, which less considered the characteristics of the medical images. Due to existing large smooth regions in medical images, Osamah et al. [24] divided medical image into smooth region and non-smooth region and applied a high embedding capacity scheme for the smooth region while applied traditional DE method for the non-smooth region. Similarity, Pai et al. [25] proposed an "region of interest" (ROI) based image hiding method which embeds secret data into non-ROI by an irreversible image hiding method and in ROIs by a reversible image hiding method. For some special medical image, Bao et al. [6] proposed tailored reversible data hiding schemes for the electronic clinical atlas by exploiting its inherent characteristics, and Huang et al. [26] proposed a histogram shifting method for image reversible data hiding for high bit depth (16 bit) medical images.

For medical image processing, many literatures have pointed out that the change places and profiles are the interesting area in the medical image [27], namely, restoring the details information can improve image quality and help for accurate diagnosis. Motivated by this idea, this paper aims to enhancing contrast of texture area while embedding data reversibly. Based on this goal, opposite to traditional RDH methods, the proposed method use two techniques for improving image visual quality. One is give priority of modifications to PEs in texture regions by reversibly embedding data into two side bins of the PEH, the other one is sort pixels in a descending order based on texture degree. In addition, this paper also proposed a message sparse representation method which inspirits from the decompression idea, to code the message for decreasing the embedding distortion. This work makes two contributions: (1) Propose a message sparse representation method to code the message for improving hiding efficiency; (2) Propose a novel RDH scheme in medical images that not only can embed data reversibly but also can improve the details information of texture area in subjective perception.

This paper is organized as follows. Section 2 analyzes traditional image quality assess metric PSNR. In section 3, we elaborate the RDH scheme with enhanced contrast of texture area. The performance of the proposed method is evaluated and compared with the other methods in Section 4, and conclusion is finally presented in Section 5.

2. Analyzing of the PSNR

Peak signal-to-noise ratio (PSNR) is a traditional standard in image quality assessment (IQA). It assesses the quality of distortion image through calculating the pixel difference of the original image and distortion image, such as

$$PSNR = 10\log_{10}\frac{L_{max}^2 \times M \times N}{\sum_{m=1}^{M}\sum_{n=1}^{N}\left[L_{in}(m,n) - L_{out}(m,n)\right]^2}, \tag{1}$$

(a) Original image

(b) Distortion image 1,PSNR=30.01(dB)

(c) Distortion image 2,PSNR=30.68(dB)

(d) Distortion image 3,PSNR=29.80(dB)

Fig. 1. An example of analyzing PSNR metric.

where L_{in} is the intensity of original image; L_{out} is the intensity of distortion image; L_{max} is the maximum possible pixel intensity of the image, normally $L_{max} = 255$.

As mentioned in Section 1, PSNR is often utilized as assessing metric in RDH method. However, it can't consistent with human visual system that has been proved in the research area of IQA [21]. An example is shown in Fig. 1, which includes one original image and three distortion images, three distortion images are added with original image's similarity information, spatial information and frequency information respectively based on original image [21]. The subjective visual perceptions of three distortion images are good, bad and neutral respectively. However, their PSNR values are almost same. The reason is PSNR only calculates the pixel difference between two images, and it lacks considering the structure information between neighbor pixels.

3. Proposed method

As we know, subjective perception is the final standard for assessing image quality. In addition, image processing research had indicated that contrast enhancement is one of method for improving image quality, in which histogram stretching and histogram equalization are the two most common methods. In the present paper, we propose a RDH method in medical images with texture area enhancement based on the idea of histogram stretching. The proposed method consists of four parts: 1) rhombus prediction and texture-based sorting; 2) embedding scheme and enhancing contrast of texture area; 3) message sparse representation; 4) message extraction and cover image recovery.

3.1. Rhombus prediction and texture-based sorting

As mentioned in Section 1, many prediction methods have been applied to RDH. In order to sort the pixel according to the texture, this paper uses rhombus prediction pattern [11] to generate

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