2015 International Conference on Intelligent Information Hiding and Multimedia Signal Processing

Improving Visual Quality of Reversible Data Hiding in Medical Image with Texture Area Contrast Enhancement

Yang Yang[1,2], Weiming Zhang [1,*], Nenghai Yu [1]
1 CAS Key Laboratory of Electro-magnetic Space Information
University of Science and Technology of China
Hefei, China
Email: skyyang@mail.ustc.edu.cn, zhangwm@ustc.edu.cn, ynh@ustc.edu.cn
2 School of Electronics and Information Engineering
Anhui University
Hefei, China

***Abstract*—Opposite to most state-of-the-art reversible data hiding (RDH) methods which usually embed data into smooth area for pursuing high PSNR values of the marked image, we propose a new RDH method for improving visual quality of the details information in medical image instead of pursuing high PSNR. The proposed method embeds data into the texture area preferential by the histogram shifting (HS) method and contrast enhancement method to enhance contrast of texture area and improve the image quality in subjective perception. Our experimental results on medical images show that the proposed method can improve image quality when compared with other HS based RDH method.**

***Keywords*-Reversible Data Hiding; Visual Quality; Contrast Enhancement; Histogram Shifting**

I. 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 itself should be restored lossless [1], [2], [3]. This reversibility is important in some special scenarios such as medical imagery [4], military imagery and law forensics. PSNR is the metric for assessing quality of marked image that used in all existing RDH methods. Presently, RDH methods often use two techniques for pursuing high PSNR value, one gives priority of modification to PEs in smooth regions, the other one sorts pixels based on smooth or texture degree [5], [6]. However, PSNR only depends on the quadratic sum of difference between original image and distortion image and it is not a complete metric that consistent with human visual perception perfectly.

Recently, Wu et al [7] proposed a reversible image data hiding which improved image visual quality through enhancing contrast of cover image instead of trying to keep the PSNR value high. This method belongs to the global spatial domain contrast enhancement algorithm and it cant reveal the details information of the image. However, medical image processing research has indicated that the change places and profiles are the interesting area in the medical image [8], which means improving resolution of texture area can improve image quality for helping accurate diagnosis. Motivated by this idea, this paper aims to enhancing resolution of texture area and embedding data reversibly. Based on this goal, opposite to traditional RDH methods, we use two techniques for improving image visual quality. One is to give priority of modifying of PEs in texture regions by reversibly embedding data into two side bins of the PEH, the other one is to sort pixels in a descending order based on texture degree. In a word, the proposed RDH scheme in medical images can not only embed data reversibly but also can improve resolution of texture area in subjective perception.

II. Proposed Method

A. Rhombus Prediction and Texture-based Sorting

A more accurate prediction technique can generate prediction errors with a sharper histogram that is more suitable for RDH. Many prediction methods have been applied to RDH, this paper use rhombus prediction pattern to generate PEs, which divides all pixels of the cover image into two sets denoted as “Cross” and ”Dot” [5]. Note that the embedding process is same in the two sets, so we only describe the method in the Cross layer. The prediction value $\hat{u}_{i,j}$ is computed using its four nearest Dot pixels $(v_{i,j-1}, v_{i+1,j}, v_{i,j+1}, v_{i-1,j})$ as

$$\hat{u}_{i,j} = \left\lfloor \frac{v_{i,j-1} + v_{i+1,j} + v_{i,j+1} + v_{i-1,j}}{4} \right\rfloor . \quad (1)$$

Based on the prediction value $\hat{u}_{i,j}$ and original value $u_{i,j}$, the PEs $e_{i,j}$ is computed as

$$e_{i,j} = u_{i,j} - \hat{u}_{i,j}. \quad (2)$$

As we prefer to embed data into texture area of “Cross” set, we use a parameter to estimate the texture degree of each pixel. In this paper, the local variance (LV) is used

DOI 10.1109/IIH-MSP.2015.70

to measure the smoothness and texture degree. The *LV* for pixel $u_{i,j}$ can be computed from the neighboring pixels $(v_{i,j-1}, v_{i+1,j}, v_{i,j+1}, v_{i-1,j})$ such that

$$LV\left(u_{i,j}\right) = \frac{1}{4}\sum_{k=1}^{4}\left(\Delta v_k - \Delta \bar{v}_k\right)^2, \tag{3}$$

where $\Delta v_1 = |v_{i,j-1} - v_{i-1,j}|$, $\Delta v_2 = |v_{i-1,j} - v_{i,j+1}|$, $\Delta v_3 = |v_{i,j+1} - v_{i+1,j}|$, $\Delta v_4 = |v_{i+1,j} - v_{i,j-1}|$ and $\Delta \bar{v}_k = \left(\Delta v_1 + \Delta v_2 + \Delta v_3 + \Delta v_4\right)/4$. Smaller *LV* value means the smoother area and vice versa, so proposed method sorts pixels in descending order of *LV* values for improving image quality.

B. Data Embedding and Texture Area Contrast Enhancement

Many literatures point out that enhancing the details information of texture area can improve image quality [8]. In general, PEH can reflect the smooth and texture area of the image, in which smooth and texture area correspond to the middle and two side bins of the PEH respectively. Hence, we prior to select two sides bins of the PEH and embed data into the selected bins by utilizing histogram shifting (HS) RDH method [9] and contrast enhancement method (contrast stretching and contrast equalization) to enhance the resolution of texture area. Based on this, we summarize five steps for the embedding process.

1) Calculate the PEH. Prediction value $\hat{u}_{i,j}$ are obtained by using Eq. (1), PEH is Calculated by using Eq. (2).

2) Select the initial bins. As PEH values of two edge bins are often different, we choose small one T_m as the initialization embedded bin, such as

$$T_m = \min(\left|\min(e_{i,j})\right|, \max(e_{i,j})). \tag{4}$$

3) Select the last bins. The last embedded bins T_p is adaptively selected according to the capacity. Such as

$$\begin{aligned} &\text{minimize} \quad T_p \in (0, 1, 2, ..., T_m) \\ &\text{subject to} \quad \Big(\sum_{E=-T_m}^{-T_p} hist(E) + \sum_{E=T_m}^{T_p} hist(E)\Big) > L \end{aligned} \tag{5}$$

where $hist(E)$ means the pixel number when PE is E in image, and L is the bit number of the to be embedded data.

4) Embed all data into selected bins. All selected bins $\pm E \in [\pm T_p, \pm T_m]$ are vacated and employed for data hiding in descending order of $LV\left(u_{i,j}\right)$, in which PEs belonging to $e_{i,j} > E$ (or $e_{i,j} < -E$) are shifted to right (or left) by a shifting distance s, then data are embedded into $\pm E$ bins, and the other bins are unchanged. Such as

$$D_{i,j} = \begin{cases} e_{i,j} + s & if\ (e_{i,j} > E) \\ e_{i,j} - s & if\ (e_{i,j} < -E) \\ e_{i,j} + d & if\ (e_{i,j} = E) \\ e_{i,j} - d & if\ (e_{i,j} = -E) \\ e_{i,j} & Otherwise \end{cases}, \tag{6}$$

where s is shifting distance that empirical belongs to 1 or 2, $D_{i,j}$ is the modified PEs, d is the message bit (0 or 1) and the numbers of '0's and '1's are required to be almost equal.

5) Calculate marked image $U_{i,j}$ as $\mathrm{U}_{i,j} = D_{i,j} + \hat{u}_{i,j}$.

In order to demonstrate the embedding processing, an example is given in Fig. 1. Assume that there are 160 bits to be hidden, probability of data '1' or '0' are all 1/2, and shifting distance is set as 1. Firstly, PEH is generated according to Eqs. (1-2) as shown in Fig. 1(a); Secondly, the initial and last bins $T_m = 6$, $T_p = 5$ are obtained according to Eqs. (4-5); Thirdly, $PE_s = \pm 7$ are vacated so that $PE_s = \pm 6$ bins can be employed for data hiding as shown in Fig. 1(b); Fourthly, $PE_s = \pm 6$ bins are shifted by one or zero when hiding data d is '1' or '0' as shown in Fig. 1(c); Lastly, the progress is repeated for $PE_s = \pm 5$ bins, $PE_s = \pm 6$ are vacated and the other data are embedded by shifting $PE_s = \pm 5$ bins by one or zero as shown in Fig. 1(d) and Fig. 1(e). Fig. 1(f) shows modified PEH after shifted two times, in which maximum shifting times is $f_{\max} = 2$. Thus data are hidden and selected bins are stretched and equalized simultaneously.

As previous RDH schemes, the overflow/underflow problem of the histogram shifting method should be taken into account. Here, we define location map like this: if original pixel value is 0/255, using '0' to present; if it is modified to 0/255, using '1' to present and 4 bits to record the shifting times. The location map is compressed and its size is N_{flow}. In addition, in order to extract data and recover cover image conveniently, the proposed method replaces LSB of the first 55+N_{flow} pixels by the following auxiliary information: selected initialization bin T_m and last bin T_p, the maximum shifting times $f_{\max}$, the shifting distance s, payload size, size of compressed location map N_{flow} and compressed location map. The LSB of the first 55+N_{flow} pixels S_{LSB} is also embedded as one part of the payload.

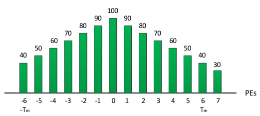
C. Data Extraction and Cover Image Recovery

The marked image is the modified Dot and Cross sets. Double decoding scheme is the inverse of the double encoding scheme. Here, we only describe the Cross decoding scheme which similar to Dot set. The extracting message and recovering of the cover image can be performed by the following five steps:

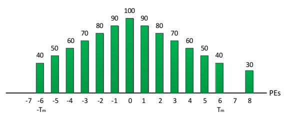
1) Read LSB of first 55+N_{flow} pixels in marked image to get the values of T_p and T_m, the maximum shift times $f_{\max}$, the shifting distance s, payload size, size of compressed location map N_{flow} and compressed location map..

2) Calculate prediction value $\hat{u}_{i,j}$ and local variance (*LV*) from Eq. (1) and Eq. (3), and sort pixels in descending order of *LV* values.

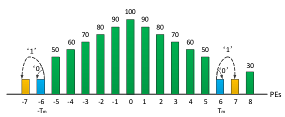
3) Calculate modified prediction error $D_{i,j} = \mathrm{U}_{i,j} - \hat{u}_{i,j}$. Search the scope of modified prediction error H_i from T_p to T_m, every time decreases one. Meanwhile, there is also a



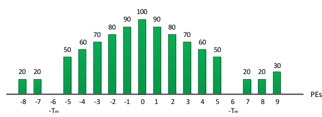
(a) Histogram of original prediction errors



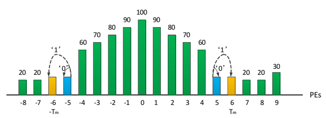
(b) Histogram of prediction errors with vacated bins



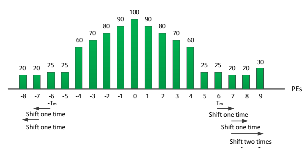
(c) Hiding data by using histogram with vacated bins



(d) Histogram of prediction errors with vacated bins



(e) Hiding data by using histogram with vacated bins



(f) Modified histogram of prediction errors

Figure 1. An example of embedding processing in PEH by proposed method

register f_i changes from 0 to $f_{\max}-1$, every time increasing one, such as

$$e'_{i,j} = \begin{cases} D_{i,j} - f_i \times s, d = 0 & if\ (D_{i,j} = H_i + f_i \times s) \\ D_{i,j} + f_i \times s, d = 0 & if\ (D_{i,j} = -H_i - f_i \times s) \\ D_{i,j} - f_i \times s - 1, d = 1 & if\ (D_{i,j} = H_i + f_i \times s + 1) \\ D_{i,j} + f_i \times s + 1, d = 1 & if\ (D_{i,j} = -H_i - f_i \times s - 1) \\ D_{i,j} & \begin{matrix} if\ (D_{i,j} < H_i + f_i \times s)\& \\ (D_{i,j} > -H_i - f_i \times s) \end{matrix} \end{cases} . \tag{7}$$

After looping $T_m - T_p + 1$ times, all secret data d are extracted. In order to recovery cover image losslessly, prediction errors that larger than T_m or less than $-T_m$ should also be recovered as

$$e'_{i,j} = \begin{cases} D_{i,j} - f_{\max} \times s & if\ (D_{i,j} > T_m + (f_{\max} - 1) \times s + 1) \\ -D_{i,j} + f_{\max} \times s & if\ (D_{i,j} < -T_m - (f_{\max} - 1) \times s - 1) \end{cases} . \tag{8}$$

4) Recover the cover image as $u_{i,j} = \hat{u}_{i,j} + e'_{i,j}$.

5) Replace the LSB of first 55+N_{flow} pixels by the S_{LSB} that extracted from step 3.

III. Experiments and Results

In order to illustrate the characteristic of the proposed method, we first do experiment on image "Lena" by respectively using the proposed's, Sachnev et al.'s [5] and Wu et al's [7] methods. The embedding rate is chosen as 0.5 and shifting distance s is empirically determined as 2. Fig.2 shows zoomed-in sections of marked "lena" images for revealing the details information of the texture area. Compared to Sachnev et al.'s and Wu et al.'s methods, the proposed method shows clearly in texture area, such as hat's decorative pattern and feathers. Sachnev et al.'s method is a typical smooth-priority RDH method and Wu et al.'s method enhances the global contrast of the image but not the local details information. However, the proposed method aims at enhancing resolution of the texture area.

In practice application, contrast enhancement of texture areas is crucial in medical image processing. Hence, we do a series experiments on magnetic resonance medical images that derived from National Cancer Imaging Archive (NCIA) [10]. Here, we choose pelvic cavity image as an example, the results are shown in Fig. 3. In order to demonstrate the performance, the proposed method is compared with Sachnev et al.s method [5] which is a typical smooth-priority RDH method. As a representative example, Fig. 3 shows marked images by using Sachnve et al.'s and the proposed method when embedding rate are 0.1bpp, 0.5bpp and 0.9bpp respectively. In the proposed method, shifting distance s is empirically determined as 2. With the increment of embedding rate, marked image's texture areas that used Sachnve et al.'s method are almost unchanged, however the proposed method restores the details information of texture areas by enhancing contrast. The reason is that the proposed method embeds data into texture areas by adaptive stretching and equalizing the contrast rather than embeds data into smooth areas as in Sachnve et al's scheme.

We also calculate the PSNR for all marked images. With the increment of embedding rate, PSNR values by using Sachnve et al. and the proposed method are all decreased as all traditional RDH method. When embedding rate is small, such as 0.1bpp, the difference of PSNR between Sachnve et al.'s method and the proposed method is very large, which is opposite to the subjective perception in Figs. 3(a,b) . This is because the proposed method selects two side bins of PEH to hide data, so large pixel difference is produced. As PSNR largely depends on the quadratic sum of difference between original image and distortion image, this large PSNR difference proves PSNR is not a metric consistent with human visual perception perfectly.

IV. Conclusion

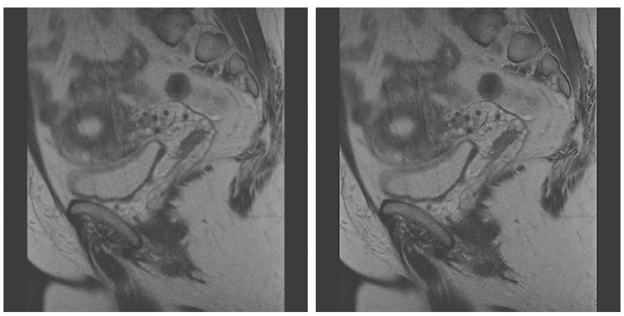
The proposed method not only enhances contrast of texture area but also hides secret dada into cover image reversibly. The main strategies employed by the proposed method is prior modifying two sides bins of PEH by using HS method. Experimental results confirmed that the marked medical image by the proposed method looks more clearly in texture area than other typical smooth-priority RDH method, and the details information are restored clearly even in low embedding rate. Coding the message for decreasing the embedding distortion will be further investigated for improvement.

Acknowledgment

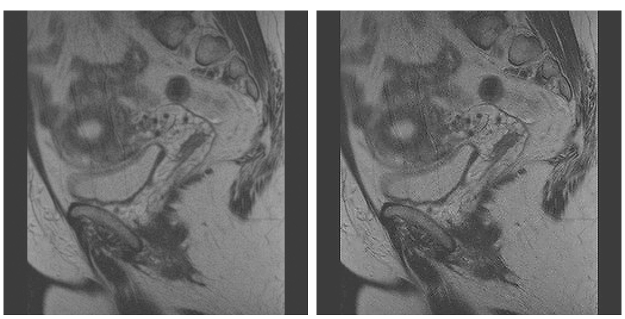
This work was supported in part by the Natural Science Foundation of China under Grant 61170234, by the Doctoral Scientific Research Foundation of Anhui University under

(a) Original image (b) Sachnev et al.[5] (c) Wu et al.[7] (d) Proposed method

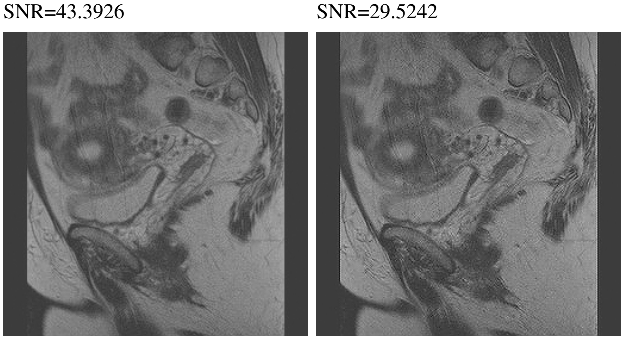
Figure 2. Zoomed-in sections of marked "lena" images by three methods in 0.5bpp



(a) Sachnev et al.[5], Bpp=0.1, PSNR=60.2826 (b) Proposed method, Bpp=0.1, PSNR=36.5090



(c) Sachnev et al.[5], Bpp=0.5, PSNR=43.3926 (d) Proposed method, Bpp=0.5, PSNR=29.5242



(e) Sachnev et al.[5], Bpp=0.9, PSNR=36.2938 (f) Proposed method, Bpp=0.9, PSNR=27.5584

Figure 3. Texture area contrast-enhanced of Pelvic cavity images by using the Sachnev et al.s and proposed methods in 0.1bpp, 0.5bpp, 0.9bpp respectively

Grant J01001319, and by the Backbone Teacher Training Program of Anhui University.

References

[1] F. Willems, D. Maas, and T. Kalker, "Semantic Lossless Source Coding," 42nd Annual Allerton Conference on Communication, Control and Computing, Monticello, Illinois, USA, pp. 1411-1418, (2004).

[2] W. Zhang, X. Hu, N. Yu, et al. "Recursive Histogram Modification: Establishing Equivalency Between Reversible data Hiding and Lossless Data Compression," IEEE Trans. on Image Processing. vol. 22, no. 7, pp. 2775-2785, (2013).

[3] C. Qin, C. C. Chang, Y. H. Huang, et al., "An Inpainting-Assisted Reversible Steganographic Scheme Using a Histogram Shifting Mechanism," IEEE Trans. on Circuits and Systems for Video Technology. vol.23, no.7, pp. 1109-1118, (2013).

[4] F. Bao, R. H. Deng, B. C. Ooi, et al., "Tailored Reversible Watermarking Schemes for Authentication of Electronic Clinical Atlas," IEEE Trans. on Information Technology in Biomedicine, vol. 9, no. 4, pp. 554-563, (2005).

[5] V. Sachnev, H. J. Kim, J. Nam, S. Suresh, and Y. Q. Shi, "Reversible Watermarking Algorithm using Sorting and Prediction," IEEE Trans. on Circuits and Systems for Video Technology, vol.19, no.7, pp. 989-999, (2009).

[6] X. Li, B. Yang, and T. Zeng, "Efficient Reversible Watermarking Based on Adaptive Prediction-Error Expansion and Pixel Selection," IEEE Trans. on Image Processing, vol. 20, no. 12, pp. 3524-3533, (2011).

[7] Hao-Tian Wu, Jean-Luc Dugelay, Yun-Qing Shi, "Reversible Image Data Hiding with Contrast Enhancement," IEEE Signal Processing Letters, vol. 22, no. 1, pp. 81-85, (2015).

[8] John B. Zimmerman, Stephen M. Pizer, Edward V. Staab, et al,, "An Evaluation of the Effectiveness of Adaptive Histogram Equalization for Contrast Enhancement," IEEE Trans. on Medical Image, vol. 7. no. 4, (1988).

[9] Z. Ni, Y. Shi, N. Ansari, and S. Wei, "Reversible Data Hiding," IEEE Trans. Circuits Syst. Video Technol., vol. 16, no. 3, pp. 354-362, (2006).

[10] National Cancer Imaging Archive. Available at https://imaging.nci.nih.gov/.