A Novel Digital Watermarking Algorithm for Medical Color Image

Xinde Sun
Department of Computer Science and Application,
Zhengzhou Institute of Aeronautical Industry Management,
Zhengzhou 450015,China
e-mail: sunxinde@zzia.edu.cn

Abstract—**In this paper, we propose a novel medical color image digital watermarking algorithm, which can realize watermark capacity, transparency and robustness effective compromise. We encrypt the watermark image by Arnold Transform at first and then take it into a random sequence. The principal component of medical image is divided into some sub-blocks with 4×4 and each block is transformed by DCT. One bit of watermark is embedded by comparing the size of specific DCT coefficients in the adjacent sub-blocks. Watermark can be extracted without the original medical image. The experimental results show that the digital watermarking algorithm has a high transparency and big capacity as well as certain robustness.**

Keywords-medical color image; watermarking; blind detection; transparency; PCA

I. INTRODUCTION

With the development of medical imaging technology and the popularity of the hospital information network, digital medical image is an increasingly wide range of applications in the medical health, but also plays an increasingly important role. Digital medical image is an important part of electronic patient records(EPR), whose security plays a pivotal role in the development of medical information. However, because electronic data have easy to modify and ease to copy characteristics, Medical image security problem is the key issue in the development of medical information [1,2]. Therefore, the study of medical image digital watermarking technology is very necessary [3].

Taking patient personal information and doctor's diagnosis or pathology classification information to be embedded in patient medical image, can not only strengthen the confidentiality of patient information, and consistency of medical image and diagnosis, but also can be convenient to management of medical image. Medical image is bound by stringent legal and ethical constraints in medical diagnosis. Therefore medical image digital watermarking is more restrictive than the general image digital watermarking. For example, the embedded watermark does not affect the disease diagnosis, should have high transparency.

There are three main categories medical image digital watermarking method. The first class method is to divide the medical image into the regions of interest, i.e. lesions ROI (region of interested) and the area of unconcern ROB (region of background).The transparency of ROB may be moderately lower, but the image quality of ROI must be ensured [2]. The second class method is use of the reversible watermarking, that image can be fully restored after watermark removed. However, the amount of watermark data embedded is smaller. The third method is to increase transparency by improving general watermarking method. Three methods have their pros and cons. In first method the common practice is to take a rectangular ROI, however, due to the different form of the lesions, obviously it exists insufficient. In the second method, the transparency can be high, but the watermark robustness is low, and the embedded data are less. For general watermarking method, the amount of embedded data is large, but the transparency is not ideal. B. M. Planitz discusses the possibility of embedding a watermark in the image in different areas using different methods [5], but did not give a specific solution. G. Coatrieux et al proposed a realization transparent watermark scheme based medical image [6], but transparency is not high enough. [7] proposed a medical images authentication algorithm, its transparency is relatively high, but it is not comprehensive enough to consider the characteristics of medical images.

This paper presents a new color medical image blind watermarking method based on DCT, which has achieved a high transparency and large amount of data embedded compromise, and has certain robustness. In this algorithm we at first using Arnold Transform encrypt watermark image, generate a bipolar random watermark sequence by descending dimension and BPSK encoding. Then we take principal component analysis on color medical image, take Discrete Cosine Transform(DCT) on the principal component sub-blocks, embed watermark by comparing the size of specific DCT coefficients in the adjacent sub-blocks. The watermark can be extracted without the original image. The proposed medical image watermarking algorithm has better performance and is practical.

II. DIGITAL WATERMARKING ALGORITHM

There are two common watermark embedding methods about color image. One method is embedding a watermark into a monochromatic component of the RGB image, another method is that RGB image is firstly converted into a YUV image, and then watermark is embedded in the luminance component *Y*. In order to improve the performance of digital watermarking, a new watermark embedding method based on Principal Component Analysis(PCA) [8] in this paper.

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A. Principal Component Analysis of Digital Image

Principal Component Analysis(PCA), also known as Karhunen-Loeve(K-L) transform, is a commonly used method in digital image processing. By using PCA, an RGB image is divided into three components independent of each other. Each component is a gray image. The principal component contains most information of the original image and can represent all characteristics of original image. If we embed watermark in the principal component, the watermark will have high transparency.

The transform matrix A of an RGB medical image can be computed by using the following formula.

$$A = \begin{pmatrix} \mu_1^T \\ \mu_2^T \\ \mu_3^T \end{pmatrix} \tag{1}$$

We denote P_1, P_2 and P_3 as the three components. For one pixel (i,j),there is an equation as follows.

$$\begin{pmatrix} p_1(i,j) \\ p_2(i,j) \\ p_3(i,j) \end{pmatrix} = A \begin{pmatrix} R(i,j) \\ G(i,j) \\ B(i,j) \end{pmatrix} \tag{2}$$

In this equation P_1 is the principal component. The three components (P_1、P_2、P_3) are unrelated.

Otherwise, if knowing three components and transform matrix A, we can compute R,G,B as follows.

$$\begin{pmatrix} R(i,j) \\ G(i,j) \\ B(i,j) \end{pmatrix} = A^{-1} \begin{pmatrix} P_1(i,j) \\ P_2(i,j) \\ P_3(i,j) \end{pmatrix} \tag{3}$$

B. DIGITAL WATERMARK SEQUENCE GENERATION

In this paper, we choose the binary image as original watermark to be embedded for the watermark's intuitiveness. The process of generating a digital watermark sequence is as follows.

a) the binary image is scrambled by Arnold transform. So the watermark can be encrypted, and the security and transparency of the watermark can be somewhat improved because of removal of the correlation between the image pixels.

b) The encrypted watermark image is converted into a watermark sequence by reducing dimension operation. The sequence is a pseudo-random sequence.

c) The watermark sequence is encoded in accordance with the BPSK, and becomes a bipolar watermark sequence, represented as *Ws*, is composed of 1 and -1. *Ws* is random, and helpful for watermarking security.we dennote the *Ws* length as L_w.

C. WATERMARK EMBEDDING

The watermark sequence *Ws* is embedded by bit in DCT coefficients of the color medical image principal component. The specific steps are as follows.

a) The watermark embedding area *Area* is selected from the principal component P_1. Its size is determined by L_w.

b) *Area* is divide into sub-blocks of 4 × 4. The number of sub-blocks is at least equal to 2 times L_w.

c) DCT is performed for all sub-blocks.

d) One specific middle frequency coefficient is extracted from DCT coefficients of each sub-block and build up one-dimensional array *Lac*. Each element position of *Lac* corresponds uniquely to a sub-block. The elements number of *Area* equal to the number of sub-blocks.

e) By comparing the size of the two adjacent elements of *Lac*, 1 bit watermark information is embedded. The specific embedding rules are

If the i-th bit of watermark to be embedded is 1, i.e., $Ws(i)=1$,and $Lac(2i-1)<Lac(2i)$ $(i=1,2,3,\ldots L_w)$, then positions of $Lac(2i-1)$ and $Lac(2i)$ are exchanged.

If the i-th bit watermark to be embedded is -1, i.e., $Ws(i)=-1$, and $Lac(2i-1)>=Lac(2i)$, then positions of $Lac(2i-1)$ and $Lac(2i)$ are exchanged.

Other cases, do not exchange positions of $Lac(2i-1)$ and $Lac(2i)$.

After L_w times comparisons, the L_w bits information contained in watermark sequence will be fully embedded in the *Lac*.

f) According to the corresponding relationship of the array *Lac* elements position and the sub-blocks, the sub-blocks specific middle frequency coefficients of DCT are replaced by the elements of the *Lac*.

g) IDCT is performed for all sub-blocks, and reconstruct the watermark embedding region *Area*, and restore the principal component P_1 according to the *Area* position information.

h) The RGB image containing watermark is reconstructed by (3).

D. WATERMARK EXTRACTION

a) We compute the principal component P_1 of the color medical image embedded watermark.

b) We select watermark embedding region *Area* from P_1 ,and divide *Area* into sub-blocks, and extract a middle frequency coefficient from the DCT coefficients of each sub-block, and then constitute a one-dimensional array *Lac*.

c) By comparing the size of the two adjacent elements of array *Lac*, the watermark sequence *Ws* can be extracted. The specific extracting rules are

If $Lac(2i-1)>Lac(2i)$,then $Ws(i)=1$;

If $Lac(2i-1)<=Lac(2i)$,then $Ws(i)=-1$.

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d) Taking sequentially decoding, increasing dimension and decrypting by Arnold transform on watermark sequence *Ws*, so we can get the watermark image.

III. DIGITAL WATERMARKING PERFORMANCE EVALUATION

A. The transparency of digital watermarking

There are two objective criteria to evaluate the transparency of the watermark, i.e. Peak Signal Noise Ratio(*PSNR*) and Structural Comparison(*SC*).

PSNR is defined as

$$PSNR\ (I, I_w) = 10\ \log_{10}\left(\frac{(2^p - 1)^2}{MSE}\right) \quad (4)$$

$$MSE\ (I, I_w) = \frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}(I(i,j) - I_w(i,j))^2 \quad (5)$$

In (4) and (5), I denote the original image and I_w denote the watermarked image, p is the image depth, usually equal to 8, the size of image is $M \times N$. The higher the image *PNSR* is, the better the transparency of the watermark is.

SC can evaluate quality of the watermarked image from another angle. It is defined as

$$SC(I, I_w) = \frac{\sigma_{II_w} + K}{\sigma_I \sigma_{I_w} + K} \quad (6)$$

σ_I and σ_{I_w} are respectively the standard deviation of the original image and the watermarked image, σ_{II_w} is the correlation coefficient of the two images, K is a constant, and meet the $SC \in [-1,1]$. The closer to 1 *SC* is, the higher the watermark transparency is.

B. Watermark capacity

In the case of having transparency, the maximum amount of data that can be embedded in an image is called a watermark capacity. Under normal circumstances, if the data amount of watermark is large, the watermark transparency will be reduced. The watermark capacity and transparency should be simultaneously taken into account in medical image watermarking applications. The capacity rate C defined in [6] is more scientific in fact.

$$C = \frac{\text{number of bits embedded in a image}}{\text{number of pixels in a image}} \quad (7)$$

It represents the average number of bits embedded in one pixel.

C. The bit error rate (BER)

It is requested as true as possible to extract the watermark in actual applications. The *BER* is an objective criterion to measure the extracted watermark quality. It is defined as

$$BER = \frac{\text{number of bits of the error}}{\text{total number of bits of watermark}} \quad (8)$$

IV. THE EXPERIMENTAL RESULTS

In this paper, we completed the simulation experiment in MATLAB environment. The embedded watermark is a 32 × 32 binary image; color medical image is a 354 × 396 brain CT image. Figure 1 shows a medical image and its counterpart after embedding. From the visual point of view, no any trace of the watermark can be seen. The objective criteria, *PSNR*=93.75dB,*SC*=1, *BER*=0, show that the transparency is higher and the extracted watermark has no distortion.

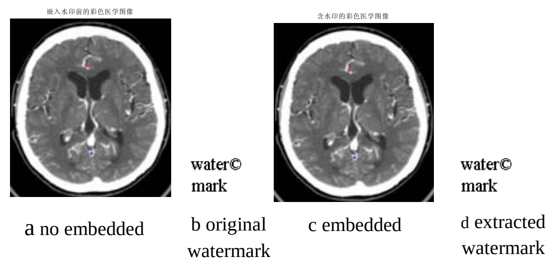

Figure 1. The transparency experimental results

Table Ⅰ is the test results of separately embedded in different amount of data in the same size image. The size of image is 354×396.Table 1 shows that with the amount of embedded data increasing, *C* is increasing, *PNSR* is decreasing, but *PSNR* also keeps higher value.

TABLE I. EMBEDDING DIFFERENT AMOUNT DATA IN ONE IMAGE

embedded data(bits)	**484**	**1024**	**1764**
C	0.0035	0.0073	0.0126
PNSR(dB）	99.39	93.75	88.41
SC	1.00	1.00	1.00

Table Ⅱ shows that, with the image size increasing, the amount of embedded data can be increased, however the *PNSR* maintains a relatively high value, and is slowly increasing. This shows that the algorithm achieves unification of the large amount of embedded data and high transparency.

TABLE II. COMPARISON OF THE LARGEST EMBEDDED AMOUNT DATA OF DIFFERENT SIZE IMAGES

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size of image	**283× 317**	**531× 594**	**708× 792**	**885× 990**	**1062× 1188**
embedded data(bits)	1024	4096	7056	11236	16384
C	0.0114	0.0130	0.0126	0.0128	0.0130
PNSR(dB)	87.61	91.56	94.91	95.88	97.92

We also do a watermark attack experiment with JPEG compression and salt and pepper noise. When the compression ratio is 20:1, we can still preferably extracted watermark, and *BER* of watermark is only 0.0098. This shows that the watermark can have both high transparency and certain robustness.

This algorithm compared with the classical algorithms from [6] and [7].The results show in Table Ⅲ.In the case of the capacity rate *C* close to the [6], this algorithm *PSNR* is increased nearly 1 times.

TABLE III. COMPARISON WITH OTHER ALGORITHMS

Algorithm	***C*(bpp)**	***PSNR*(dB)**	**Complexity**
This paper	Maximum 0.03	93.75	Lower
[6]	0.04~0.18	48.13~49.11	Higher
[7]	0.015	66	Higher

Experimental data in this paper objectively show that the digital watermark algorithm has low image distortion, high transparency and certain robustness.

V. CONCLUSION

In this paper, the algorithm realizes watermark capacity, transparency and robustness effective compromise. The principal component analysis, sub-block divided and medium frequency coefficient selection are the key to improve the performance of the watermarking algorithm. The algorithm provides a scheme to resolve color medical image security problem. Embedding doctor and patient information in electronic patient records can enhance patient information confidentiality, ensure medical image and diagnostic consistency.

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