Robust Watermarking Technique Used in Medical Volume Data

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ABSTRACT

Medical volume data are always concerned with the breach of confidentiality. A robust watermarking technique, resisting conventional attack, is proposed in this paper. The watermarking technique is a zero-watermarking. Firstly, the original watermarking image scrambling opts to use a novel Chebyshev chaotic neural network. Secondly, the medical volume data are split into 64 non-overlapping sub-volume data, each of which is done by sub-block three-dimensional (3D) discrete cosine transform so as to obtain the direct-current components. Thirdly, the 64 direct-current components are subjected to standardized processing. Finally, the 64-bit feature vector is generated by the perceptual hashing, which is used for producing zero-watermarking.Therefore, the watermarking technique has a good robustness resisting conventional attacks. The results show that the watermarking technique used in medical volume data is effective. So the watermarking technique is suitable for medical volume data concerned with privacy protection, safety and management.

Keywords: Chebyshev chaotic network, medical volume data, robust, watermarking

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INTRODUCTION

Digitization is widely used in the medical field (1). Medical diagnostic equipment produce a lot of digital medical images everyday (2, 3). Owing to the development of communication technology, particularly the wide use of the Internet, more and more medical images are transmitted in the public network (4). When a patient's medical image is transmitted through the network, it may disclose the patient's personal information. With the development of the Internet, it becomes more and more urgent to protect patients' personal information, like magnetic resonance imaging (MRI) and other medical images of their personal information, as well as patiens' electronic medical record data from being leaked (5, 6).

Digital watermarking technique is one kind of information security technology, which can be applied to image integrity authentication and image copyright protection (7). As an emerging technology that can be used to protect multimedia data, digital watermarking technology has been developed rapidly in recent years, and is a hot topic in the international academic community (8, 9). In recent years, research on medical image watermarking technology has attracted researchers'attention (10–12). The problems can be resolved effectively by medical image digital watermarking technology. By means of medical image watermarking (MIW), specific identification information is embedded into carrier images, so that the authenticity and integrity of the authentication of medical images, electronic patient record (EPR) hiding and copyright protection can be realized.

The initial digital watermarking technology is the copyright protection for digital media on the Internet (13). Now, the usage of digital watermarking invisibility and robustness can keep patients' personal information hidden in the medical images to ensure secure transmission on the Internet. When patients' information is transmitted over the Internet, the use of MIW can prevent data tampering and protect privacy (14). Currently, most of the objects of the study of MIW are two-dimensional (2D) plane images. The studies on medical volume data watermarking technique are few. At present, most of the medical images (*eg* MRI, *etc*) are 3D volume data (15). Thus, research on medical volume data watermarking technique can guarantee the safety of the transmission of medical images, having great theoretical and practical significance.

A novel robust watermarking technique for the purpose of protecting medical images is presented in this study. It is based on chaotic neural network, sub-block 3D discrete cosine transform and perceptual hashing. The watermarking technique has sub-block 3D discrete cosine transform, transformation properties and robustness of perceptual hashing, which can stand up to a variety of conventional attacks.

METHODS

The robust watermarking for medical volume data includes: zero-watermarking construction process and zero-watermarking extraction process. Figure 1 displays the zero-watermarking construction process. The zero-watermarking extraction process is shown in Figure 2.

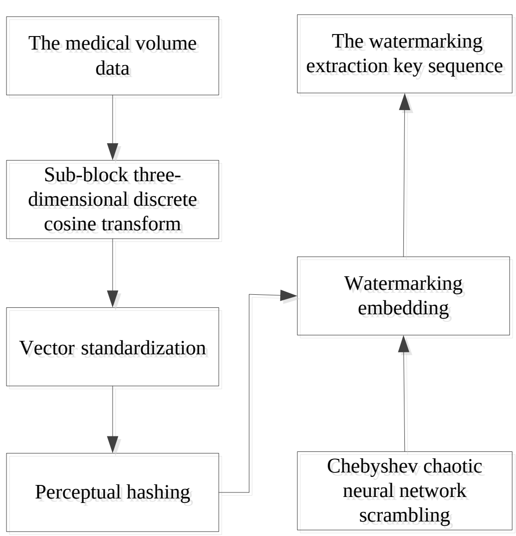

Fig. 1: The construction process.

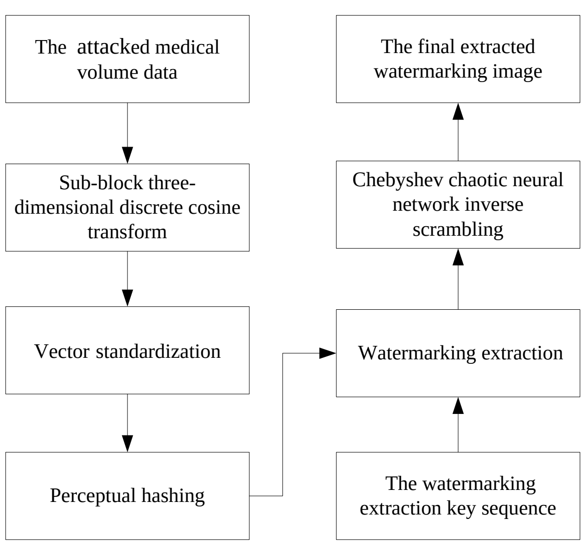

Fig. 2: The extraction process.

Sub-block 3D discrete cosine transform

Discrete cosine transform is an important method which simplifies Fourier transform and is an important transform in digital image processing (16–18). A lot of important image algorithms are based on the discrete cosine transform. Meanwhile, the discrete cosine transform algorithm with computing speed, high precision, is easy to implement in a digital signal processor. Currently, it has been widely used in image processing and has become a series of image coding international standard core part. The 3D discrete cosine transform is basically the 2D discrete cosine transform extension. Its transform formula is as follows.

$$F(u,v,w) = c(u)\times c(v)\times c(\omega)\times\left[\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\sum_{z=0}^{P-1} f(x,y,z) \times\cos\frac{(2x+1)u\pi}{2M}\times\cos\frac{(2y+1)v\pi}{2N}\times\cos\frac{(2z+1)\omega\pi}{2P}\right] \tag{1}$$

where *f* (*x*, *y*, *z*) is 3D volume data on the data values in the (*x*, *y*, *z*), *f* (*x*, *y*, *z*)'s 3D discrete cosine transform coefficients are *F* (*u*,*v*,*w*). $\mu= 1, 2, \ldots, M-1$; $v= 1, 2, \ldots, N-1$; $\omega= 1, 2, \ldots, P-1$.

$$c(\mu) = \begin{cases} \sqrt{1/M} & \mu = 0 \\ \sqrt{2/M} & \mu = 1, 2, \cdots M-1 \end{cases} \tag{2}$$

$$c(\upsilon) = \begin{cases} \sqrt{1/N} & \upsilon = 0 \\ \sqrt{2/N} & \upsilon = 1, 2, \cdots N-1 \end{cases} \tag{3}$$

$$c(\omega) = \begin{cases} \sqrt{1/P} & \omega = 0 \\ \sqrt{2/P} & \omega = 1, 2, \cdots P-1 \end{cases} \tag{4}$$

where $c(\mu)$, $c(v)$and $c(\omega)$are the coefficients in formula (1).

Its inverse transform formula is as follows .

$$f(x,y,z) = \left[\sum_{\mu=0}^{M-1}\sum_{\upsilon=0}^{N-1}\sum_{\omega=0}^{P-1} c(u)\times c(v)\times c(\omega)\times F(u,v,w) \times\cos\frac{(2x+1)u\pi}{2M}\times\cos\frac{(2y+1)v\pi}{2N}\times\cos\frac{(2z+1)\omega\pi}{2P}\right] \tag{5}$$

In this study, the original medical volume data were divided into 64 sub-volume data. Each sub-volume data was transformed using the 3D discrete cosine transform so as to obtain the direct-current components, because the direct-current components are strongly robust.

Vector standardization

The standard formula is as follows.

$$S = \frac{O - m}{\eta} \tag{6}$$

where *S* is the standardization vector; *O* represents the original vector; *m* is the original vector of the mean; η represents the original vector of the standard deviation.

Perceptual hashing

Definition 1: Perceptual hashing is a brief summary of media perception content, which is a class of unidirectional mappings from multimedia data sets to multimedia perception abstract sets. The generated digital summary is called the perceptual hashing value. The mapping process is also known as a hashing generation process, which is accomplished using the one-way function. The one-way function is shown in the formula (7).

$$Hash = H\left(I, K\right) \tag{7}$$

where *Hash* represents the image content, namely the hashing value which, in general, binary vector is used to express; *H* is the perceptual hashing function; *I* represents the image; and *K* represents the encryption key for the hashing process.

Chebyshev chaotic neural networks scrambling

A Chebyshev chaotic neural network was adopted in this study (19). Its model is expressed in Fig. 3. The excitation function of the hidden layer chooses Chebyshev orthogonal polynomials

(19). The Chebyshev chaotic neural network produces the chaotic sequence for scrambling. Its performance is very close to the ideal chaotic sequence.

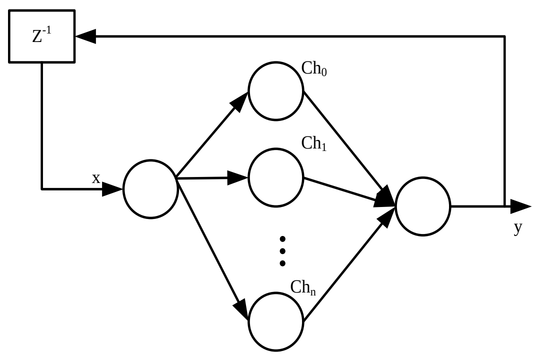

Fig. 3: Chebyshev chaotic neural network.

RESULTS

The watermarking technique used in medical volume data was tested and verified in Matlab 2010a. The original medical volume data were taken from the matlab 2010a's own nuclear magnetic resonance 3D image volume data (MRImat). The size of the original medical volume data is 128 × 128 × 27 (Fig. 4). Its 2D slice image sequence is shown in Fig. 4(a). Its 3D medical volume data are shown in Fig. 4 (b).

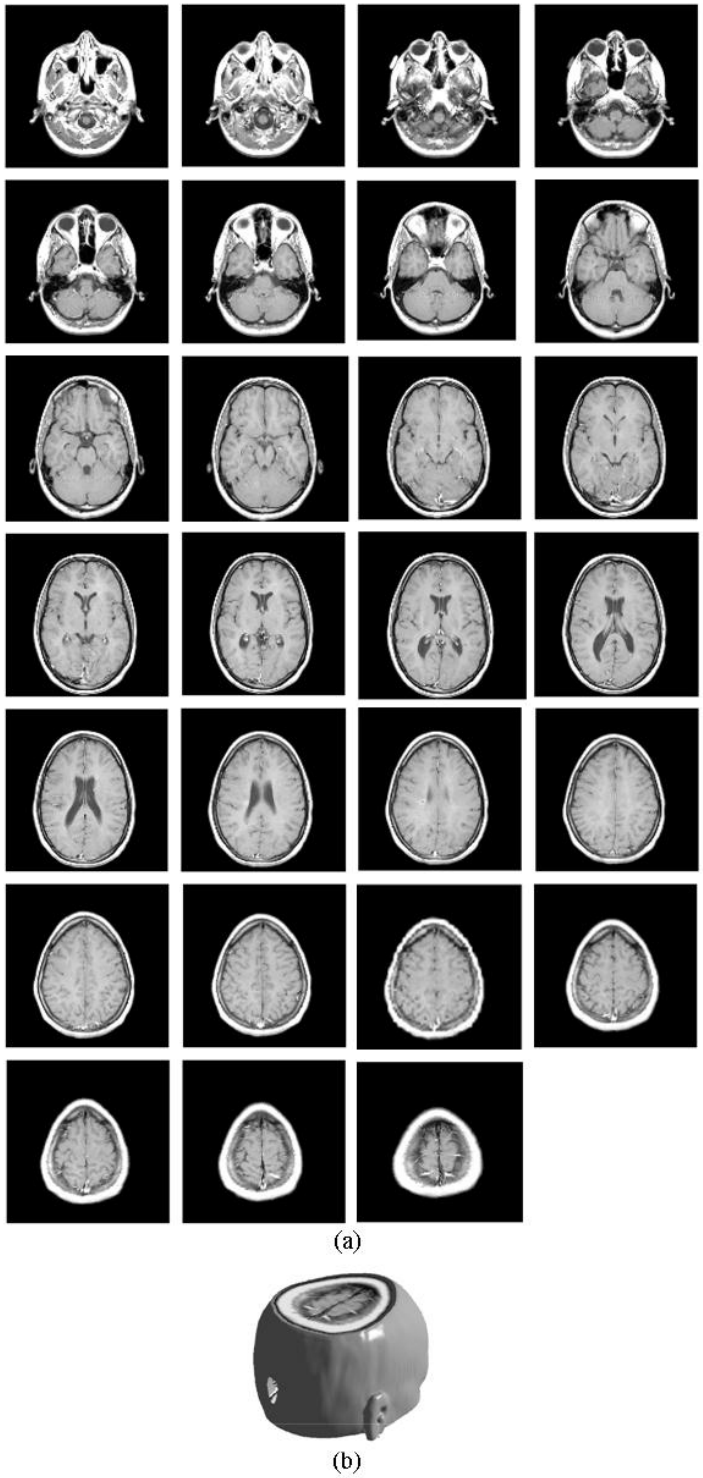

Fig. 4: The original medical volume data, (a) 2D slice image sequence and (b) original 3D medical volume data.

The original watermarking image and scrambled watermarking image are shown in Figs 5 (a) and (b), respectively.

(a) (b)

Fig 5: The watermarking image.(a) original watermarking image and (b) scrambled watermarking image.

(1) JPEG attack.

Medical volume data are performed with JPEG attack, whose factor is 6%. The image processing result is shown as Figs. 6(a), (b) and (c). As can be seen from Fig. 7 (a), although the compression quality factor is relatively small, the degree of correlation is still 1. So, the watermarking is very robust against JPEG attack.

(2) Median filtering attack.

Median filtering is a nonlinear smoothing technique. Medical volume data are attacked by (5 × 5) median filtering. When the filtering number is ten times, the corresponding image processing result is shown as Figs. 6 (d), (e) and (f). Fig.7 (b) illustrates that the watermarking has a good anti-median filtering attack robustness.

(3) Gauss noise attack.

The Gauss noise intensity coefficient measures the added noise interference size in medical volume data. The Gauss noise intensity is 20%. Fig. 6: (g), (h) and (i) describe the corresponding image processing result.

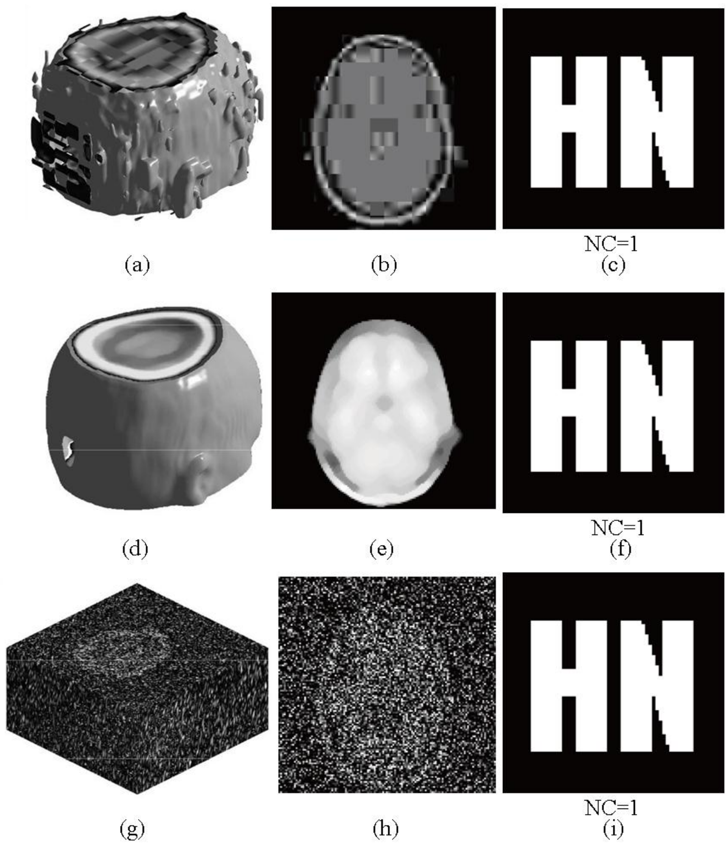

Fig. 6: Experimental images under conventional attacks.(a) Medical volume data under JPEG attack, (b) Slice image under JPEG attack, (c) Extracted watermarking image under JPEG attack, (d) Medical volume data under median filtering attack, (e) Slice image under median filtering attack, (f) Extracted watermarking image under median filtering attack, (g) Medical volume data under Gauss attack, (h) Slice image under Gauss attack and (i) Extracted watermarking image under Gauss attack.

The watermarking has better anti-Gaussian noise immunity as can be seen in Fig. 7(c).

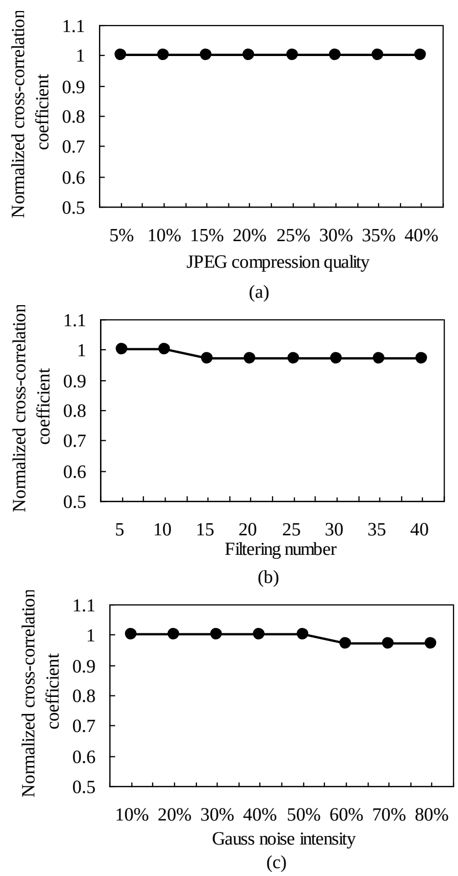

Fig.7: Robustness under conventional attacks. (a) normalized cross-correlation coefficient under under JPEG compression attack, (b) normalized cross-correlation coefficient under median filtering attack and (c) normalized cross-correlation coefficient under Gauss attack.

Table 1: Comparison of the proposed technique with the medical image watermarking techniques in (20−22)

Technique	Object	Medical image content	Embedding technique	Blind	Robustness
(20)	2D image	Change	Haar wavelet and karhunen loeve transforms	Yes	Yes
(21)	2D image	Change	Wavelet transform and singular value decomposition	No	Yes
(22)	2D image	Change	Frequency and spatial domains	Yes	Yes
The proposed technique	3D volumes	Unchanged	Zero-watermarking	Yes	Yes

DISCUSSION

At present, the research object of medical image watermarking technique is mostly 2D image. And the research on the 3D medical volume data is scanty. However, the medical images produced by the existing medical equipment are mostly three-dimensional medical volume data. In this study, the watermarking for 3D medical volume data has important practical value. It can well solve the medical image copyright protection and security issues, enhance the security of medical information system and provide security for telemedicine.

The proposed technique was compared with the technique of others (20–22), and the results are given. The advantages and disadvantages of the comparative method are listed in Table 1. Hajjaji *et al* Lei *et al*, Al-Hayet and Amer Hajaja have demonstrated robust wartermark in their experimental results (20–22). Each robust water marking technique can well resist conventional attacks, has good robustness and security, and can very well solve a variety of information security problems. However, it is worth mentioning that the proposed watermarking technique's object consists of 3D medical volume data. Hajjaji, Lei and Hajetu and Amer have demonstrated that robust watermarking for 2D medical image was a robust watermarking (20–22).

This watermarking was embedded into each 2D image slice. The proposed watermarking technique is zero-watermarking.The robust watermarking of this study was constructed by using the important features of the medical image, instead of modifying these features. The robust watermarking technique of this study is easy to implement, and the watermarking embedding and extracting are fast. The medical images produced by the existing medical equipment are mostly 3D medical volume data. So, this study's watermarking technique is suitable for the medical volume data concerned with privacy protection, safety and management.

CONCLUSIONS

Since medical volume data always face the problem of the breach of confidentiality, a new robust watermarking technique is proposed in order to solve the problem. This is because sub-block 3D discrete cosine transform and perceptual hashing are used to construct zero-watermarking. In essence, the robust watermarking technique does not make any changes to the original medical volume data, which has very good invisibility. So, the watermarking technique has better robustness and security.

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