A Robust Zero Watermarking Algorithm for Medical Images Based on Tetrolet-DCT

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Abstract. The rapid development of the information age of big data has promoted the development of traditional medicine and online diagnosis, as well as aroused concerns about the privacy of patient information. Aiming at the hidden dangers of copying, cutting, tampering, etc. in the dissemination of medical images, combined with the characteristics of medical images, this paper proposed a novel zero-watermarking algorithm based on Tetrolet-DCT, focusing on how to improve its security. Logistic map chaotic encryption is performed on the watermark, the Tetrolet-DCT transform is used to extract the visual feature of medical image, and the watermark information is embedded and extracted by combining the zero-watermarking technology. Experimental data show that the algorithm proposed in this paper can effectively extract the watermark without any changing of the medical image, and has a higher NC value under conventional attacks and geometric attacks. it has better invisibility and robustness.

Keywords: Zero Watermark · Tetrolet-DCT · Medical image · Robustness

1 Introduction

With the rapid development of the Internet and information technology, images, texts, videos, etc. containing important information are constantly updated and widely spread in various fields. In this process, they may be subject the problems of copying, cutting, and malicious tampering. Once tampered, it is easy to cause serious consequences, especially in the special medical field [1, 2]. Digital watermarking technology can solve this problem well.

Digital watermarking mainly realize copyright protection by embedding important information in digital media such as images, text, and audio [3]. Generally, a complete

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digital watermarking system includes three parts: watermark embedding, watermark extraction and watermark detection [4]. According to the hidden position of the watermark, digital watermarks are divided into spatial watermarks and frequency domain watermarks. LSB algorithms and patchwork algorithms are classical spatial watermarking algorithms, and transform domain watermarking algorithms are mainly based on DCT, DWT, DFT transform [5]. However, the wavelet transform can only reflect the zero-dimensional singularity of the signal. To represent and process image data more effectively, multiscale geometric analysis has gradually become a research hotspot. In the last years, researchers have proposed a series of multi-scale geometric analysis tools, such as ridgelet, curvelet, contourlet, brushlet, wedgelet, bandlet, shearlet, tetrolet, and so on. The multi-scale geometric analysis shows strong advantages and potential in the fields of image compression, denoising, enhancement, and feature extraction [6].

Medical image is a special form of image. In modern medicine, it is regarded as an important basis for diagnosis, and it is generally not allowed to be modified artificially to avoid misdiagnosis [7]. The existing watermarking algorithms for general digital images are generally less robust when applied to medical images, and basically cannot resist geometric attacks [8, 11]. Therefore, this paper proposed a novel algorithm based on Tetrolet-DCT, which combined the concept of zero watermark [14] and can quickly achieve watermark embedding and extraction on the premise of ensuring the invisibility and robustness of watermark information. Compared with wavelet transform, curving transform, contour transform and ridgelines, this method is more effective for medical images [12, 13].

2 Basic Theory

2.1 Tetrolet Transform

In 2009, Jens Krommweh proposed Tetrolet transform for sparse image representation, which is a new Haar wavelet transform, and its basic idea is simple, fast and effective. The construction of this transform is similar to wedglet transform, and Haar function is applied in the edge part, which can be expressed sparsely. Compared with wavelet, curvelet and contourlet, the transformed image coefficients are more concentrated, which can get better image quality.

Tetrolet transform was first applied to the four-frame jigsaw puzzle. The image was divided into 4 $\times$ 4 blocks, disregarding rotations and reflections there are five different shapes. In each 4 $\times$ 4 blocks, the imposition combination is performed according to the geometric information. And 22 kinds of square combinations and 117 different combinations of rotation and reflection are considered. The decomposition steps are as follows:

Suppose an image size is a $= a(a[i,j])_{i,j=0}^{N-1}$, where N = 2J, J $\in$ N which can be decomposed at the rth level r = 1, 2, 3 ..., J.

Step 1: Decompose the image into 4 $\times$ 4 blocks.

Step 2: Decompose each block by tetrolet to obtain 2 $\times$ 2 low-pass subbands and 12 $\times$ 1 high-pass subbands, then find the most sparse tetrolet representation in each block.

The low-pass subband coefficient is

$$a^{r,(c)}[s] = \sum_{(m,n)\in I_s^{(c)}} [0, L(m,n)]a^{r-1}[m,n] \tag{1}$$

The high-pass subband coefficient is

$$w_l^{r,(c)} = \left(\sum_{(m,n)\in I_s^{(c)}} \varepsilon[0, L(m,n)]a^{r-1}[m,n]\right)_{s=0}^{3} \tag{2}$$

Where r is the decomposition series, c is 117 combinations, C = 1, 2, ..., 117, $\varepsilon[l, m]$.

Step 3: Decompose the next layer and rearrange the low-pass coefficients and high-pass coefficients of each block to a 2 × 2 block.

Step 4: Save the Tetrolet decomposition coefficient (high pass part).

Step 5: Repeat steps 1–4 for the low-pass part until the decomposition is complete.

Figure 1 shows the decomposition process:

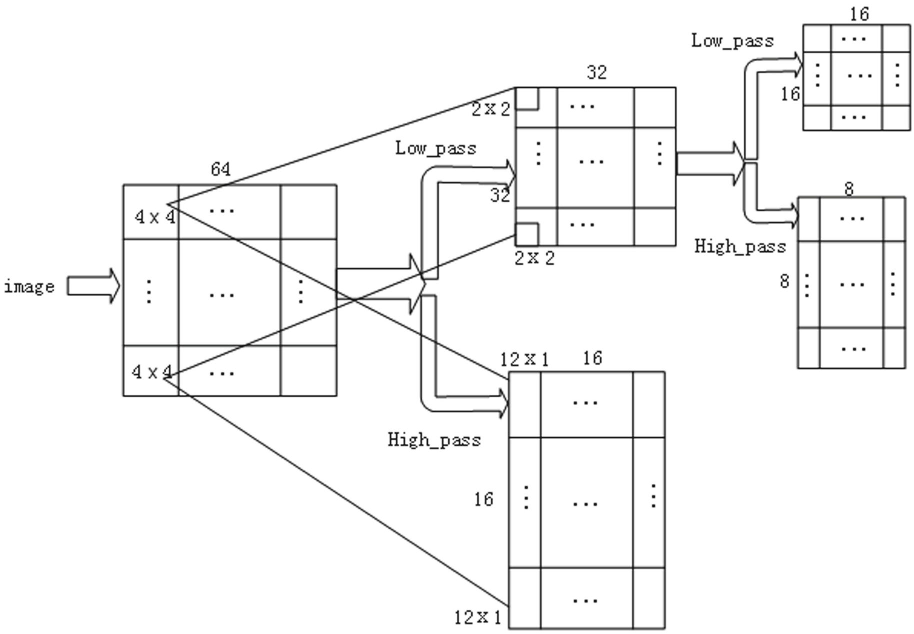

Fig. 1. Tetrolet decomposition process

As a result, Tetrolet can adapt to the geometric characteristics of the image, so the Tetrolet transform can maintain the edge and texture of the image very well, and it is very effective in image compression, denoising and nonlinear approximation.

2.2 DCT Transform

Discrete Cosine Transform (DCT) is a classic frequency domain algorithm, which is widely used in digital watermarking and image processing.

It has the advantages of fast calculation speed and high resistance to compression attacks and is compatible with international data compression standards JPEG and MPEG. According to the visual characteristics of human eyes, the characteristics of the image are mainly in the middle and low frequency of the image, so the watermark information can be embedded in the middle and low-frequency region of the image in DCT domain. A two-dimensional DCT transform is as follows:

$$F(u, v) = c(u)c(v) \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) \cos\frac{\pi(2x+1)u}{2M} \cos\frac{\pi(2y+1)v}{2N} \tag{3}$$

Among them, $u = 0, 1, ..., M - 1, v = 0, 1, ..., N - 1$;

$$c(u) = \begin{cases} \sqrt{\frac{1}{M}} & u = 0 \\ \sqrt{\frac{2}{N}} & u = 1, 2, \ldots, M-1 \end{cases}, \quad c(v) = \begin{cases} \sqrt{\frac{1}{N}} & v = 0 \\ \sqrt{\frac{2}{M}} & v = 1, 2, \ldots, N-1 \end{cases} \tag{4}$$

2.3 Logistic Map

Logistic map, also known as the wormhole model, is a very simple and classic chaotic system, which is widely used in the encryption field. The mathematical expression is:

$$x_{n+1} = \mu x_n(1 - x_n) \tag{5}$$

Where μ is the branch parameter.And when $3.5699456 < \mu \leq 4$, the logistic map is chaotic.

According to the formula, the chaotic sequence is very sensitive to the initial value. When $\mu = 4$, the probability distribution function of the Logistic chaotic sequence $\rho(x)$ is:

$$\rho = \frac{1}{\pi\sqrt{x(1-x)}}, 0 < x < 1 \tag{6}$$

It shows that the Logistic sequence is ergodic. In this paper, we set $\mu = 4$.

3 Proposed Watermarking Algorithm

3.1 Feature Extraction

We first decompose the original medical image (512 pixel × 512 pixel) by tetrolet and get the low-frequency subband and high-frequency subband. The low-frequency subband is decomposed to the next level, and the high-frequency subband is saved. We know that the image features are mainly in the low-frequency part, while the high-pass part mainly shows the texture and geometric details in all directions.

Then DCT is applied to the low-frequency part of tetrolet decomposition to obtain the feature of thr medical image. The 8-bit low and medium frequency coefficients of DCT are taken as the feature vector.

Table 1. Coefficients of medical image under different attacks (correlation coefficient: 1.0e + 04)

Image attacks	PSNR (dB)	C(1, 1)	C(1, 2)	C(1, 3)	C(1, 4)	C(1, 5)	C(1, 6)	C(1, 7)	C(1, 8)	Symbol sequence	NC
The original image	–	3.642	0.055	−1.609	−0.049	−0.016	−0.028	0.244	−0.015	11000010	1
Gaussian noise (3%)	16.24	3.812	0.048	−1.507	−0.044	−0.013	−0.025	0.234	−0.014	11000010	1
JPEG compression 30%	34.83	3.642	0.056	−1.607	−0.049	−0.019	−0.027	0.245	−0.015	11000010	1
Medianfilter [5 × 5] 10 times	28.56	3.663	0.054	−1.582	−0.052	−0.010	−0.023	0.240	−0.008	11000010	1
Scaling(×0.75)	–	2.732	0.041	−1.206	−0.036	−0.012	−0.021	0.183	−0.012	11000010	1
Movement (down 4%)	15.28	3.545	0.053	−1.572	−0.043	−0.048	−0.035	0.267	−0.008	11000010	1
Rotation (clockwise 10°)	15.60	3.512	0.137	−1.705	−0.085	−0.122	−0.096	0.136	−0.030	11000010	0.81
Y Cropping(10%)	–	3.343	0.052	−1.463	−0.043	−0.086	−0.032	0.243	−0.015	11000010	0.83

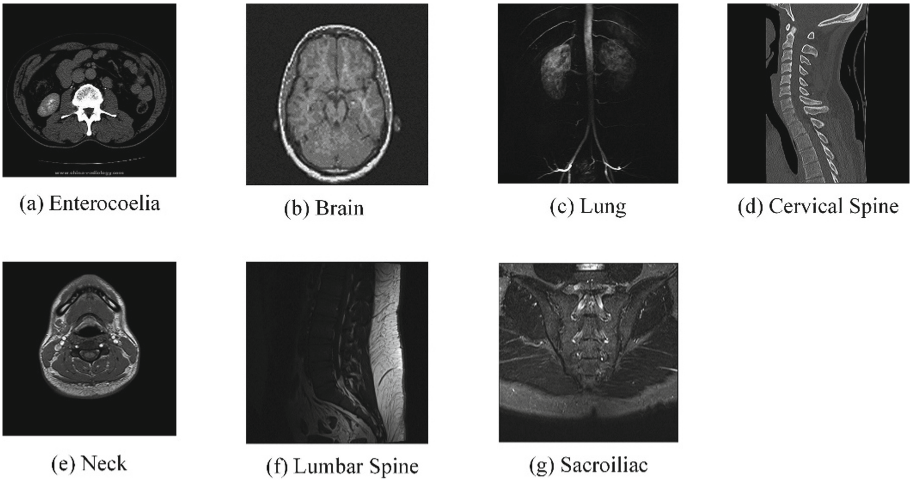

Fig. 2. Different original medical images for watermarking

Through experiments, we found that although the coefficients of the medical image changed after various attacks, the positive and negative signs of the coefficients did not change (see Table 1).

To verify the feasibility of this method, we selected 7 different medical images for comparison experiments and found that the NC value of different images is much less than 0.5, indicating that the correlation is very small, and the NC values between the same pictures are all 1.00 (see Table 2). In consequence, this method is feasible for feature extraction.

Table 2. Correlation test of seven different medical images

NC	enterocoelia	Brain	Lung	Cervical spine	Neck	Lumbar spine	Sacroiliac
enterocoelia	1.00	−0.07	−0.13	0.25	0.20	0.13	0.34
Brain	−0.07	1.00	0.18	−0.06	0.02	−0.06	0.29
Lung	−0.13	0.18	1.00	0.25	0.32	−0.12	0.08
Cervical spine	0.25	−0.06	0.25	1.00	−0.20	0.00	−0.34
Neck	0.20	0.02	0.32	−0.20	1.00	−0.07	0.36
Lumbar spine	0.13	−0.06	−0.12	0.00	−0.07	1.00	−0.08
Sacroiliac	0.34	0.29	0.08	−0.34	0.36	−0.08	1.00

3.2 Encryption and Embedding of the Watermark

Figure 3 shows the encryption process of the watermark. First, the watermark image (32 pixel × 32 pixel) is binarized to obtain $W(i, j)$. Secondly, a chaotic sequence is generated through the logical initial value $X(j)$, then carry out the ascending dimension and symbol operation on the sequence to obtain the binary encryption matrix $C(i, j)$. Then perform XOR operation on $W = (i, j)$ and $C(i, j)$ to get the encrypted watermark $BW(i, j)$.

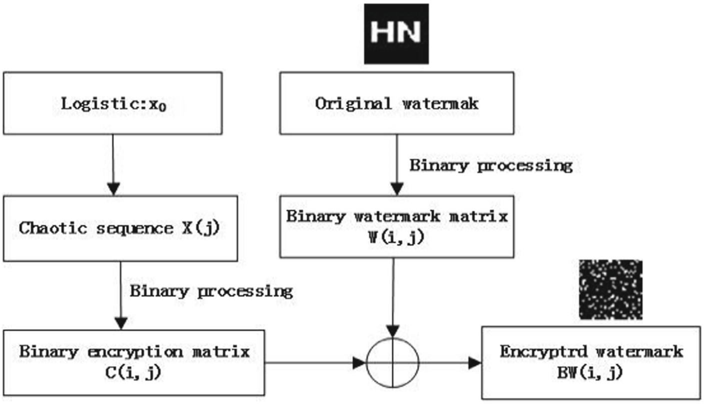

Fig. 3. Watermark encryption process

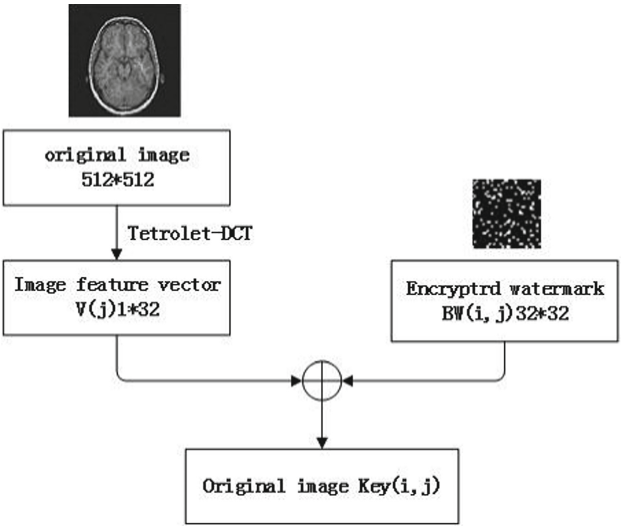

Fig. 4. Watermark embedding process

Figure 4 is the watermark embedding process. First, perform the Tetrolet-DCT transform on the medical image (512 pixel × 512 pixel) to obtain a 32 bit dimensional feature vector $V(j)$, then perform XOR operation on $V(j)$ and $BW(i, j)$ to get the key of the original medical image $K(i, j)$.

3.3 Watermark Extraction and Restoration

Figure 5 is a flow chart of watermark extraction and restoration. First, perform feature extraction on the attacked image to obtain32 bit dimensional feature vector $V'(j)$, and then perform an XOR operation with $K(i, j)$ of the original medical image to extract the watermark $BW'(i, j)$ contained in the attacked image.

Then the watermark matrix $BW'(i, j)$ and the binary matrix $C(i, j)$ are XOR to obtain the restored watermark matrix $W'(i, j)$.

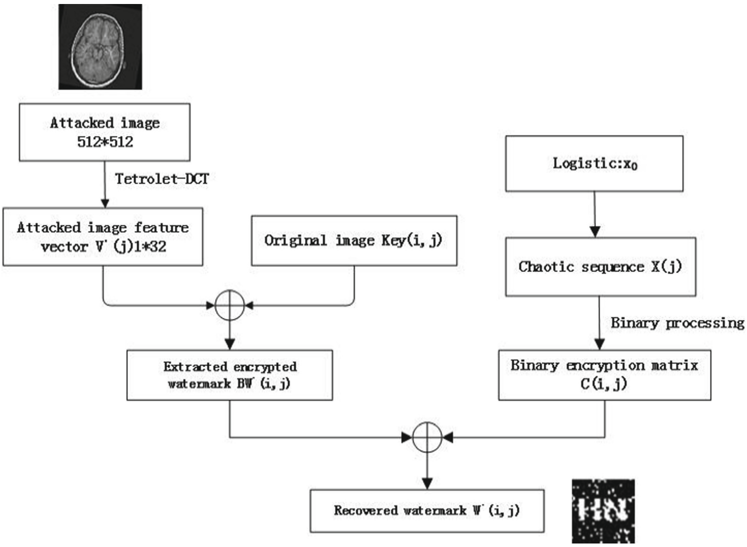

Fig. 5. Watermark extraction and restoration process

3.4 Watermark Evaluation

The performance evaluation of watermarking mainly has two indicators: imperceptibility and robustness.

Imperceptibility means that after the watermark is embedded in the original image, it does not affect the quality of the carrier image, and compared with the original image. It is difficult for the human visual system to find the difference. The peak signal-to-noise ratio(PSNR) is as follows:

$$PSNR = 10\log_{10}\left[\frac{MN\max\limits_{i,j}(I(i,j))^2}{\sum_i \sum_j (I(i,j) - I'(i,j))^2}\right] \tag{7}$$

Watermark robustness is used to judge the anti-attack ability of the watermark, which is judged by comparing the correlation between the extracted watermark and the original watermark. The formula for calculating the normalized correlation coefficient (NC) is as follows:

$$NC = \frac{\sum_i \sum_j W(i,j)W'(i,j)}{\sum_i \sum_j W^2(i,j)} \tag{8}$$

4 Experiments and Results

4.1 Experimental Data

In this paper, the Matlab R2016a platform is used for simulation, and 512 pixel × 512 pixel brain medical image and a meaningful 32 pixel × 32 pixel watermark are selected for experiments.

Table 3. Experimental data of various attacks on test images

Attacks	Parameter	PSNR	NC
Gaussian noise	5%	14.30	0.95
	10%	11.87	0.95
	15%	10.61	0.93
Median filtering	[3 × 3], 20 times	33.82	1.00
	[5 × 5], 20 times	27.46	1.00
	[10 × 10], 20 times	25.45	1.00
JPEG	1%	26.28	1.00
	5%	28.44	1.00
	10%	31.29	1.00
Rotation (clockwise)	6°	17.24	0.81
	10°	15.60	0.81
	20°	14.68	0.73
Scaling	×0.22	–	0.70
	×0.75	–	1.00
	×2.50	–	1.00
Move vertically	6%	15.03	1.00
	15%	14.28	0.76
	20%	13.78	0.65
Cropping Y direction	2%	–	0.95
	9%	–	0.83
	15%	–	0.66

The experimental data are as follows:

Generally, when the NC value is more than 0.5, it indicates that the extracted watermark is valid. The higher the NC value, the better the quality of the extracted watermark. It can be seen that the algorithm in this paper has good robustness. The data in Table 3 shows that the algorithm used in this paper has strong anti-attack performance in traditional attacks, especially in geometrical attacks such as median filtering, JPEG compression, scaling, rotation and shearing. It has the better anti-attack performance.

4.2 Performance Comparison with Other Algorithms

Table 4 shows the comparison between the algorithms in this paper and reference 15.

Table 4. Comparison results between different algorithms

Attacks	Parameter	DWT-DCT		Tetrolet-DCT	
		PSNR (dB)	NC	PSNR (dB)	NC
JPEG attack	1	26.28	0.94	26.28	1.00
	5	28.43	0.94	28.43	1.00
	10	31.29	0.94	31.29	1.00
Median filtering/10 times	[3, 3]	33.99	0.94	33.99	1.00
	[5, 5]	28.55	0.94	28.55	1.00
	[7, 7]	26.39	0.89	26.39	1.00
Gussian noise/%	2	17.77	0.89	17.77	1.00
	10	11.89	0.83	11.87	0.95
	20	9.81	0.83	9.78	0.87
Movement (down)/%	5	18.99	0.94	15.10	1.00
	10	16.19	0.94	14.73	1.00
	15	15.33	0.94	14.28	0.75
Rotation (clock wise)/°	5	18.00	0.76	18.00	0.81
	10	15.59	0.76	15.59	0.81
	15	14.86	0.68	14.86	0.81

We can find that when compared with reference [15], the proposed algorithm in this paper has advantages in traditional attacks such as JPEG compression, median filtering, and Gaussian noise. Anti-attack is more stable than DWT-DCT.

5 Conclusion

In the medical image field, this paper proposed a robust zero-watermarking algorithm based on Tetrolet-DCT, which used Tetrolet-DCT and logistic mapping to embed and extract watermark. Compared with DWT, Tetrolet has advantages in image compression, denoising, and nonlinear approximation. And robust watermarking algorithm is most commonly used for digital copyright protection and is widely used in the fields of medical images, bill anti-counterfeiting, and digital signatures, etc., which improves the security of information. Experiments show that the watermark information can be extracted effectively without any changing of the original image. The proposed algorithm is robust and can resist geometric attacks well.

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