A Comparative Study of Two Audio Watermark Embedding Algorithms

Chao Yin[1], ShuJuan Yuan[2]

1 Department of Physics and Electronics
Langfang Teachers University
Langfang, Hebei,China
2. College of Science
North China University of Science and Technology
TangShan, Hebei,China

***Abstract* - This paper presents two digital audio watermarking embedding algorithms. One is based on mean-quantization and the other is based on single-coefficient quantization. They both use a binary image as the watermark and Chaotic sequence is used to encrypt it. These two algorithms both embed watermark into the discrete wavelet transform domain of the audio, and embed the watermark by modifying some of the low-frequency coefficients in different ways. One algorithm embeds the watermark by modifying some of the low-frequency coefficients' mean, and the other one embeds the watermark by modifying a single coefficient. The watermark can be extracted without original audio signal, so they are both blind watermarking algorithms. Experimental results show that the watermarking embedding algorithm based on mean-quantization is better than the embedding algorithm based on single-coefficient quantization in general.**

Keywords -Watermark, Discrete Wavelet Transform, Mean-Quantization, Single-Coefficient Quantization, Digital Audio Signal

I. INTRODUCTION

With the manufacture and issuance of the digital AV products in quantity, the copyright protection of the audio data becomes more and more important. The copy restriction, use track and the peculation confirmation can be realized by embedding watermark into audio carrier[1]. In recent years, the research of the audio digital watermark technology is developed rapidly, especially the technology of embedding watermark in the transform domain of the

(1) Use control: It can control the user's authority by embedding watermarking into audio signal. Only someone with a permit can use or copy these products.

(2) Content authentication: By detecting the integrity of the watermark extracted, we can judge whether the audio is a complete one. For example, judge the integrity of an evidence recording in court, or judge the integrity and accuracy of the photo-taking. So our research on it is tremendously significant.

(3) Digital fingerprint: With the rapid development of information technology, digital products can be copied and transmitted easily through simple point-and-click operations. Those operations hurt legal owners greatly. By embedding watermark (digital fingerprint) into every legal copy, we can extract watermark to follow its source when the digital products are copied without permission,

(4) Secret communication: We can embed secret information into the audio carrier. Thus the secret information can't be found readily, and it has a better invisibility and security.

(5) Broadcast monitoring: After business users buying advertisements, they want to know whether the advertisement is broadcast on time. It is very expensive to

audio. It makes the research more practical, because it can embed information into sensitive area of the audio carrier.

Similar to image, the audio can also be modified to be embedded information. These modifications can't be removed easily if the attackers do not destroy the original audio. The main application areas are as follows [2] :

(1) Copyright protection: Audio watermarking is an effective way to protect the audio owner's copyright. Through embedding watermarking into audio signal, we can extract watermark to prove who is the owner when a copyright dispute happens.

employ someone to monitor it. So we can embed watermark into the audio part of the advertisement, and

(2) Information sign: We can embed some assistant information into audio signal, such as the time of sound recording and so on.

The characteristics of audio watermark are as follows[3-4]:

(1) Invisibility, which means we can't feel the change of the audio after being embedded with watermark.

(2) Fidelity, which means the watermark can't destroy the normal use of the original audio carrier.

(3) Safety, which means the watermark can't be deleted easily, and can provide copyright evidence.

(4) Robustness, which means the watermark can resist attacks to the audio signals. That is to say, we can still extract watermark even when the audio is attacked.

(5) Watermark capacity, which means the maximum data quantity of the audio system.

II. PROPOSED SCHEME

In recent years, the research on digital audio watermark technology has developed rapidly.

At an earlier time, there are four algorithms in time domain-Least significant bits(LSB), echo hiding, phase coding and spread-spectrum method[5].

But also, we can embed watermark into transform domain of the audio signal, such as Discrete Wavelet Transform Domain, Discrete Cosine Transform Domain and Discrete Fourier Transform Domain.

There are several watermark embedding methods, such as addition principle, subtraction principle[6], mean quantization, single-coefficient quantization and so on.

Addition principle is expressed by equation(1) and subtraction principle is expressed by equation(2).

$$x'(k) = x(k) + \alpha \cdot w(k) \tag{1}$$

$$x'(k) = x(k)\left[1 + \alpha \cdot w(k)\right] \tag{2}$$

Where $x(k)$ is an audio amplitude in time domain or a coefficient in transform domain; $x'(k)$ is a modified one; α is a parameter predetermined; $w(k)$ is a watermark bit.

Here we discuss two watermarking embedding algorithms, one is called single-coefficient quantization embedding algorithm and the other is called mean-quantization embedding algorithm.

Single-coefficient quantization method is as follows[7-8]:

The quantization principle diagram is shown in Figure.1.

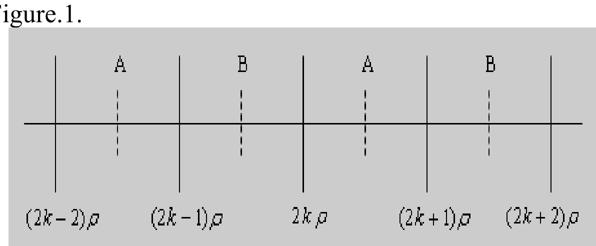

Figure 1. The quantization principle

Where f is a coefficient to be embedded or modified, and f' is a modified one.

We separate the coefficients into two kinds of intervals: A and B. k is an integer and ρ is quantization step. w is a watermark bit. If w is 1, f is quantized to the nearest middle of A. Otherwise, f is quantized to the nearest middle of B

Modular arithmetic is expressed by the following equations.

$$m = f \bmod \rho \tag{3}$$

$$r = f - m\rho \tag{4}$$

Where m is the quotient of modular arithmetic, and r is the remainder.

The quantization process is as follows.

If $f \geq 0$, and $w = 1$, thus

$$f' = \begin{cases} (2k + \frac{1}{2})\rho & m = 2k \\ (2k + \frac{1}{2})\rho & m = 2k + 1 and \left|r\right| \leq \frac{1}{2}\rho \\ (2k + 2\frac{1}{2})\rho & m = 2k + 1 and \left|r\right| > \frac{1}{2}\rho \end{cases} \tag{5}$$

If $f \geq 0$,and $w = 0$, thus

$$f' = \begin{cases} (2k + 1 + \frac{1}{2})\rho & m = 2k + 1 \\ (2k - \frac{1}{2})\rho & m = 2k and \left|r\right| \leq \frac{1}{2}\rho \\ (2k + 2\frac{1}{2})\rho & m = 2k and \left|r\right| > \frac{1}{2}\rho \end{cases} \tag{6}$$

If $f < 0$, and $w = 1$, thus

$$f' = \begin{cases} -(2k + 1 + \frac{1}{2})\rho & m = -(2k + 1) \\ -(2k - \frac{1}{2})\rho & m = -2k and \left|r\right| \leq \frac{1}{2}\rho \\ -(2k + 2\frac{1}{2})\rho & m = -2k and \left|r\right| > \frac{1}{2}\rho \end{cases} \tag{7}$$

If $f < 0$, and $w = 0$, thus

$$f' = \begin{cases} -(2k + \frac{1}{2})\rho & m = -2k \\ -(2k + \frac{1}{2})\rho & m = -(2k + 1) and \left|r\right| \leq \frac{1}{2}\rho \\ -(2k + 2\frac{1}{2})\rho & m = -(2k + 1) and \left|r\right| > \frac{1}{2}\rho \end{cases} \tag{8}$$

By above knowable, the maximum error of coefficient after quantization is ρ , and we call it quantified coefficient. The bigger the quantified coefficient is, the stronger the watermark's robustness is and the worse of the invisibility of the watermark. In contrast, the smaller the quantified coefficient is, the better the invisibility of the watermark is and the weaker of the robustness is. So we must choose an appropriate one.

When extracting, if the coefficient value is in the interval of A, then we get the watermark bit of; Otherwise we get the watermark bit of 0. And then we change the watermark bits into a square matrix which is the extracted watermark.

Mean-quantization method is as follows:

Here we assume A_4 is a set whose elements are chosen to be embedded or modified. We divide these elements into a matrix, whose number of lines is represented by K and the number of rows is represented by L, and each row's mean value is calculated and is represented by $\overline{Y}(l),(l=0,1,\cdots L-1)$. Calculate $z(l)$ using equation (9).

$$z(l)=\lfloor \overline{Y}(l)/Q_1+1/2\rfloor ,l=0,\cdots L-1 \quad (9)$$

Where the symbol of $\lfloor\ \rfloor$ represents the operation of rounding down. Q_1 stands for a parameter predetermined, called quantization step.

We embed watermark like this:

If

$$z(l)\%2=w(l) \quad (10)$$

Where the symbol of % represents the operation of modular arithmetic, and $w(l)$ is the remainder.

thus

$$\overline{Y^*}(l)=Z(l)\times Q_1 \quad (11)$$

Where $\overline{Y^*}(l)$ stands for the new mean of each row.

If

$$z(l)\%2\neq w(l) \quad (12)$$

and

$$z(l)=\lfloor \overline{Y}(l)/Q_1\rfloor \quad (13)$$

then $$\overline{Y^*}(l)=(z(l)+1)\times Q_1 \quad (14)$$

If $$z(l)\%2\neq w(l) \quad (15)$$

and $$z(l)\neq \lfloor \overline{Y}(l)/Q_1\rfloor \quad (16)$$

then

$$\overline{Y^*}(l)=(z(l)-1)\times Q_1 \quad (17)$$

This algorithm extracts the watermark without the original audio, so it is an open and blind watermark embedding algorithm. Same as the embedding process, the audio signal being embedded with watermark is also decomposed with the same wavelet basis as the one when embedding. Extract the watermark from low-frequency coefficients which is represented by a set of A_4, and change it into a matrix; Calculate the mean of each column, and each mean is represented by $\overline{Y'}(l)$.

The extracted watermark bit is represented by $w'(j)$. Calculate $w'(j)$ using the following equation (18).

$$w'(j)=\lfloor \overline{Y'(l)}/Q1+1/2\rfloor \%2,\ l=0,\cdots L-1 \quad (18)$$

Change $\{w'(j)\}$ into a two-dimensional image and then we get the extracted watermark.

This paper presents two blind audio watermark embedding algorithms in DWT domain of the audio signal. The audio signal is decomposed by appropriate wavelet basis and the low-frequency coefficients are chosen to be embedded.

Why we embed watermark into the discrete wavelet transform domain of the audio?

Because discrete wavelet transform has its own characteristic features:

(1)Multiscale, which can be used to analog characteristics of human auditory system;

(2)Wavelet transform is adept at analyzing audio signals with its time-frequency localization ability;

(3)Various basic functions provide us with flexible and diversified schemes;

(4)It has fast algorithms.

Based on the characteristics above, we choose discrete wavelet transform domain to embed watermark. So it is a very effective tool for us to research on embedding algorithms.

The block diagram of embedding process is shown in Figure.2.

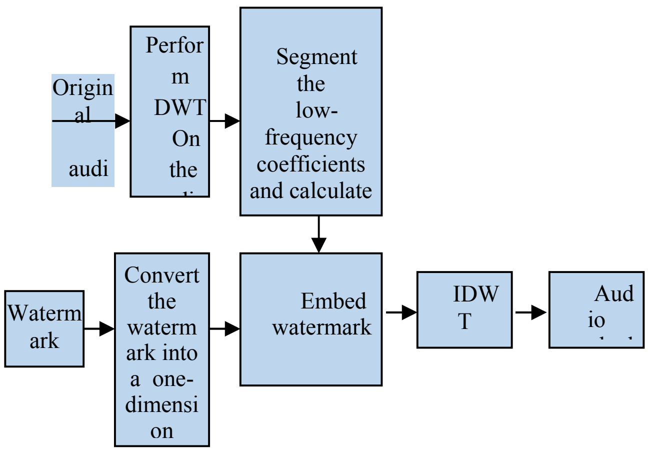

Figure 2. The block diagram of embedding process

1. Choose a planar image as watermark, and convert it into a one-dimensional sequence in order to embed watermark bits into audio signal in mono.

$$V=\{v(k)=w(i,j),0\le i<M1,0\le j<M2,k=i\times M2+j\} \quad (19)$$

Where the one-dimensional sequence is represented by V; $w(i,j)$ is a watermark bit; M_1 is the number of lines of the planar image; M_2 is the number of rows of the planar image.

2. In order to ensure the safety of the watermark, we need to disorder the watermark with a chaotic sequence. Chaos system[9-10] is sensitive to initial value and it has many good characteristics similar with white noise. So it is usually used to encrypt image. We gets the binary chaotic sequence of $\{h(k)\}$ using Logistic chaos mapping, and

assume that $\{v_p(k)\}$ represents the disordered watermark sequence.

$$v_p(k) = v(k) \oplus h(k) \tag{20}$$

3. Perform discrete wavelet transform process on the audio signal. The audio signal is decomposed with an appropriate wavelet basis. A_4 is a set composed of low-frequency coefficients after the audio signal is decomposed for 4 levels using Daubechies-3 wavelet basis, and D_1 is a set composed of high-frequency coefficients after the audio signal is decomposed for 1 level using Daubechies-3 wavelet basis.

4. Embed watermark using mean-quantization method [11-12]. The elements of A_4 are chosen to be embedded with watermark in order to guarantee the robustness of the watermark.

5. Perform discrete wavelet inverse-transform and then get the audio signal being embedded with watermark information.

The extracting process is as follows:

The block diagram of extracting process is shown in Figure.3.

III. SIMULATION RESULTS

In this part, we give the experimental results based on MATLAB.

We choose a 12 seconds length' pop music in these simulation experiments. Its sampling frequency is 44.1 kHz and its resolution is 16bit. Considering the complexity of this algorithm, the audio signal is decomposed for 4 levels using Daubechies-3 wavelet basis. The watermark is 64×64 binary image.

SNR is used to evaluate the invisibility of the watermarks[13].

Figure 3. The block diagram of extracting process

$$SNR = 10 * \log_{10}\left(\frac{\sum_{k=1}^{N} I^2(k)}{\sum_{k=1}^{N}\left[I(k) - I'(k)\right]^2}\right) \tag{21}$$

Where $I(k)$ stands for an original audio sampling value; $I'(k)$ stands for an audio sampling value after embedding watermark; N stands for the number of sampling value.

The experimental results based on single coefficient quantization algorithm is as follows. In this experiment, the SNR of the audio signal having been embedded is 34.9732 dB, and we can't distinguish the differences between the original audio and the audio having been embedded.

The experimental results based on mean quantization algorithm is as follows. According to mean quantization principle, the higher the K value is, the stronger the robustness of the watermark system will be and the lower the capacity will be. Experimental results show that when the K value is over 8, the robustness can' be improved evidently. To ensure the capacity and stronger robustness of the watermark, K value is 8 and the quantization step is 0.02 in these experiments.

In these experiments, the SNR of the audio signal having embedded is 37.9743 dB, and we can't distinguish the differences between the original audio and the audio having been embedded.

To test the robustness of the watermark, the music is attacked as follows[14]:

(1) Add white Gaussian noise whose mean value is zero and variance is 0.002 to the audio signal.

(2)Add coloured noise which is obtained by processing white noise with a band pass filter whose frequency range is from 300 Hz to 3400 Hz.;

(3) Process the audio with a low-pass filter, whose cut-off frequency is 20 kHz;

(4) Requantize: change the audio's resolution from 16bits to 8 bits, and then change its resolution from 8 bits to 16 bits again;

(5) Denoise the audio with one-dimensional discrete stationary wavelet transform method ;

(6) Cut a tenth part of the audio randomly;

(7) Median filter;

(8)MP3 compression: Compress the audio' bits rate to 128 kbit/s.

(9)Down-sample the audio: Change the audio' sampling frequency from 44.1KHz to 22.05KHz, and than change the audio' sampling frequency from 22.05 kHz to 44.1 kHz again.

(10)Up-sample the audio: Change the audio' sampling frequency from 44.1KHz to 48KHz, and than change the audio' sampling frequency from 48KHz to 44.1KHz again.

The extracted watermarks based on single-coefficient quantization algorithm are shown in Figure.4.

The extracted watermarks based on mean-quantization algorithm are shown in Figure.5.

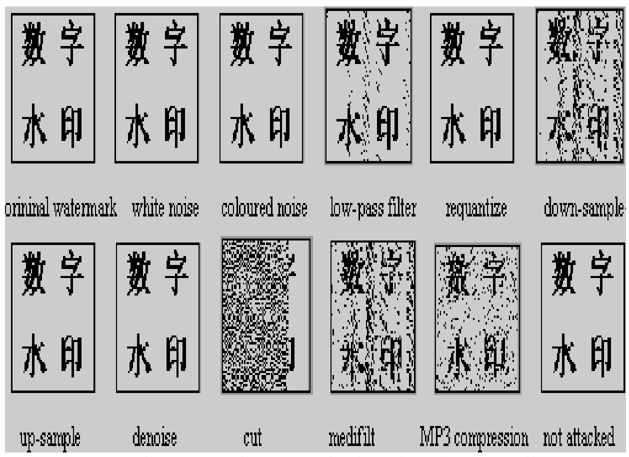

Figure 4. The extracted watermarks based on single-coefficient quantization

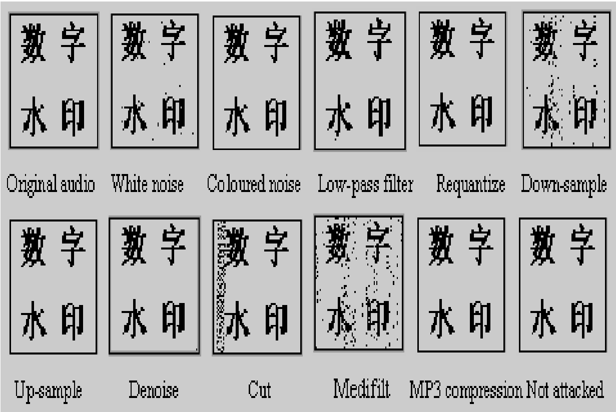

Figure 5. The extracted watermarks based on mean-quantization.

There are three methods to evaluate the quality of the watermark.

(1) Subjective listening testing: To test the quality of the watermark, we use Subjective Difference Grade (SDG) for subjective listening testing [15], which is shown in table I.

In these experiments, We let ten persons listen to the music having been embedded with watermark. At last, these ten people gave the grade of 0.0. The nearer the given mean of grade approaches zero, the better the invisibility is. (2) Bit-error ratio (BER)

We also can use BER to evaluate the robustness of the watermark. BER is the ratio of the wrong bits number of the watermark to the total number bits.

(3) Normalized cross-correlation coefficient (NC)

NC is used for evaluating the similarity between the original watermark and the extracted watermark.

$$NC(W,W') = \frac{\sum_{i=1}^{M_1}\sum_{j=1}^{M_2} w(i,j)w'(i,j)}{\sqrt{\sum_{i=1}^{M_1}\sum_{j=1}^{M_2} w(i,j)^2}\sqrt{\sum_{i=1}^{M_1}\sum_{j=1}^{M_2} w'(i,j)^2}} \tag{22}$$

Where stands for an original watermark bit; represents a extracted watermark bit. is the number of lines of the watermark ; is the number of rows of the watermark.

TABLE I SUBJECTIVE DIFFERENCE GRADE (SDG) FOR SUBJECTIVE LISTENING TESTING

SDG	Description
0.0	Imperceptible
-1.0	Perceptible, but not annoying
-2.0	Slightly annoying
-3.0	Annoying
-4.0	Very annoying

IV. CONCLUSION

In this paper, two digital audio watermarking embedding algorithms are proposed: One is based on single-coefficient quantization, and the other is based on mean-quantization. The two algorithms' simulations are carried out in the same conditions: Use the same musics; Choose the same two-dimensional binary image as watermark, and encrypt the binary image with a chaotic sequence to ensure the security of watermark; Embed watermark into the discrete wavelet transform domain (DWT) of the audio signal by modifying some low-frequency coefficients. Original audio signal is not necessary when extracting, so they are blind algorithms. The only difference between them is the embedding algorithm. In the MATLAB simulation experiments, we get a conclusion that the mean-quantization algorithm is better than single-coefficient quantization algorithm in general.

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