

FFT-Based Audio Watermarking Method with a Gray Image for Copyright Protection

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Abstract

Many effective watermarking algorithms have been proposed and implemented for multimedia. Human auditory system (HAS) is far more complex and sensitive than human visual system (HVS). For this reason, a few algorithms have been proposed for audio watermarking. In this paper, a new method of embedding gray image data into the audio signal and additive audio watermarking algorithm based on Fast Fourier Transformation (FFT) domain is proposed. First, the original audio is transformed into FFT domain. The FFT coefficients are divided into a fixed number of subsections and the energy of each subsection is calculated. Next, watermark is generated from gray image. Watermarks are then embedded into selected peaks of highest energy subsection. Experimental results demonstrate that the watermark is inaudible and this algorithm is robust to common operations of digital audio signal processing, such as noise addition, re-sampling, re-quantization and so on. To evaluate the performance of the proposed audio watermarking method, subjective and objective quality tests including Similarity (SIM) and Signal to Noise ratio (SNR) are conducted.

Keywords: *Audio watermarking, Fast Fourier Transformation, Arnold Transformation, SNR, SIM*

1. Introduction

Along with the rapid growth of Internet, the distribution of audiovisual media becomes easier. It leads to the problems regarding copyright protection. Among them, copyright protection is the primary concern and the hotspot of international area in recent areas. Digital product information hiding and digital watermarking technology is generated on this basis and developed along with the protection of copyright; this technology is widely used in protecting the copyright of image, audio and video by means of extracting or detecting the watermark for its various application including copyright protection, broadcast and publication monitoring, authentication, copy control. Audio watermarking should satisfy the following features. They are as following:

- I. Imperceptibility: The digital watermark should not affect the quality of original audio signal after it is watermarked.

- II. **Robustness:** The embedded watermark data should not be removed or eliminated by unauthorized distributors using common signal processing operations and attacks.
- III. **Capacity:** Capacity refers to the numbers of bits that can be embedded into the audio signal within a unit of time.
- IV. **Security:** Security implies that the watermark can only be detectable by the authorized person.

In this paper, we propose a new watermarking technique using Fast Fourier Transformation (FFT) for audio copyright protection. The watermarks are embedded into the selected peaks of the highest energy segment of FFT coefficients. Experimental results indicate that the proposed watermarking method provide strong robustness against several kinds of attacks such as noise addition, re-sampling, re-quantization and so on. In addition, our proposed method achieves SNR (signal-to-noise ratio) values ranging up to 45 dB.

The rest of the paper is organized as follows: Section 2 provides a brief description of previous works related to audio watermarking. Section 3 introduces traditional Arnold transformation. Section 4 introduces our proposed watermarking method including watermark embedding process and watermark detection process. Section 5 and 6 discusses the performance of our proposed method in terms of imperceptibility and robustness. Finally, section 7 concludes this paper.

2. Related Research

A significant number of watermarking techniques have been reported in recent years in order to create robust and imperceptible audio watermarks. Lie et al. [1] propose a method of watermarking system for audio signals in the time domain. This proposed algorithm uses differential average-of-absolute-amplitude relations. In which samples are kept in group and each group of audio samples uses to represent one-bit information. This method also uses the low frequency amplitude modification technique so that it can scale the amplitudes in selected sections of samples. In [2], authors propose a blind audio watermarking method which inserts watermark into audio signal in the time domain. For watermark detection, the strength of the audio signal modifications is limited by the necessity for producing an output signal. The watermark is generated using a key. The watermark embedding also depends on the amplitude and frequency of audio signal so that it minimizes the audibility of the watermarked signal. In [3], authors explain a blind watermarking method which inserts watermarks into Discrete Cosine Transform (DCT) coefficients using quantization index modulation method. In [4], authors propose a blind audio watermarking method by using adaptive quantization against synchronization attack. In addition the multiresolution characteristics of discrete wavelet transform (DWT) and the energy compression characteristics of discrete cosine transform (DCT) are combined in this method. It also improves the transparency of digital watermark. Watermark is then inserted into low frequency components using adaptive quantization according to human auditory system (HAS). In [5], authors propose a watermarking method in cepstrum domain for audio signal in which a pseudo-random sequence is used as a watermark. The watermark is then weighted in the cepstrum domain according to the distribution of cepstrum coefficients and the frequency masking characteristics of human auditory system (HAS). In [6], authors propose a blind watermarking system which takes the advantages of the attack-invariant feature of the cepstrum domain and error-correction capability of BCH code to increase the imperceptibility and robustness of audio watermarking. In [7], authors propose a survey of watermarking

systems which are applied to Multimedia. In [8], watermarks are embedded into the highest m DCT coefficients of the whole sound excluding the DC component by the following equation:

$$v'_i = v_i(1 + \alpha x_i) \quad (1)$$

Where, m is the length of the watermark sequence, v_i is a magnitude coefficient into which a watermark is embedded, x_i is a watermark to be inserted into v_i , α is a scaling factor, v'_i is an adjusted magnitude coefficient. The watermark sequence is extracted by performing the inverse operation of (1) represented by the following equation:

$$x_i^* = \left(\frac{v_i^*}{v_i} - 1\right) / \alpha \quad (2)$$

In [9], the authors introduce a new method for inserting watermarks into audio signals by using components which have low frequency. This proposed method uses lifting-based wavelet transform (LBWT). The novel technology of inserting image data into the audio signal and additive audio watermarking algorithm based on DCT domain is proposed in [10]. In [11], the authors propose a watermarking method where DCT coefficients are used. In [12], the authors introduce a watermarking method which inserts synchronization signals in time domain. In [13] and [14], the authors propose a new watermarking system using Discrete Fourier Transform (DFT) and First Fourier Transform (FFT) of digital contents for copyright protection respectively. In [15], the authors propose a novel method to generate a unique personalized watermark which can act authenticating information for any watermarking algorithm. In [16], the authors describe the watermark construction process where scrambled version of watermark is obtained with the help of Arnold transform.

3. Traditional Arnold Transform

A digital image can be considered as a two unit function $f(x,y)$ in the plane Z . It can be represented as $Z = f(x,y)$ where $x,y \in \{0,1,2,3,\dots,N-1\}$. Hence, N represents order of digital image. The matrix of image can be changed into a new matrix by using the Arnold transform which results in a scrambled version to offer better security. It is a mapping function which changes a point (x,y) to another point (x', y') by using the equation (3) and (4).

$$x' = (x + y) \bmod N \quad (3)$$

$$y' = (x + 2y) \bmod N \quad (4)$$

If the original image iterative n times to come to some scrambled state, the scrambled image also need to iterative n times using new anti-Arnold transform to come to original image.

4. Proposed Watermarking Method

In this section, we propose our algorithm based on a Fast Fourier Transform (FFT) on audio signal in which a watermark image is embedded. The algorithm consists of two process; watermark embedding process and watermark extraction process.

4.1. Watermark Embedding Procedure

The embedding process performs three major operations; watermark pre-processing, FFT-based frequency decomposition of the audio signal and watermark embedding in the FFT-transformed audio signal. The operations are described in the following steps.

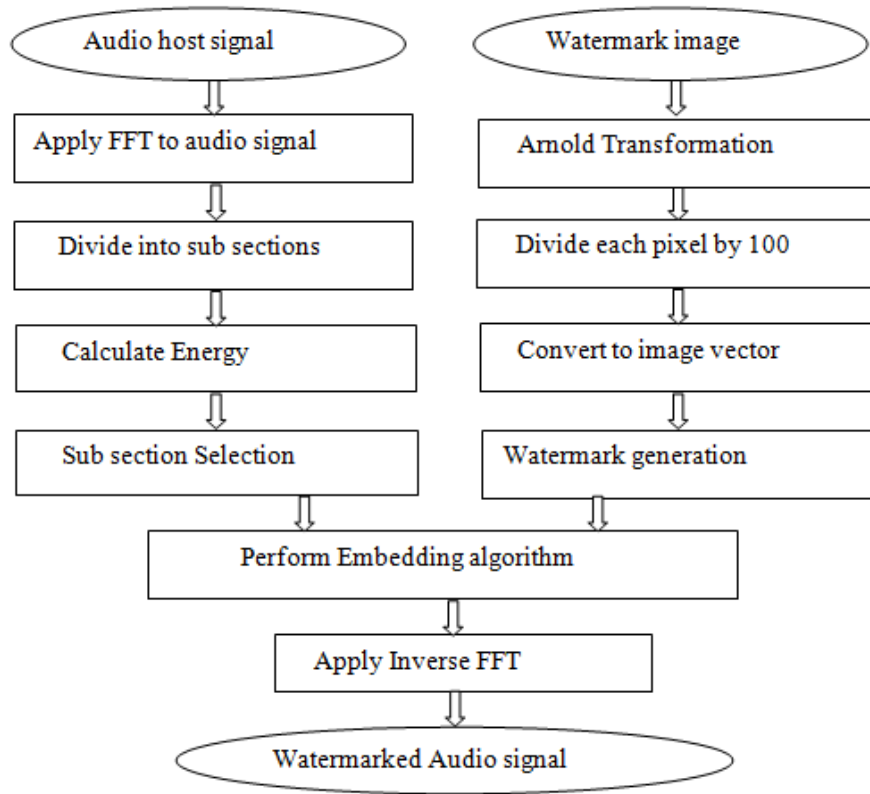


Figure 1. Watermark Embedding Process

1. Express the gray-scale watermark image as a two-dimensional matrix whose size is $M1 \times M2$.

$$\text{Image} = \{ \text{Image}(k,j) , 0 \leq k < M1, \quad 0 \leq j < M2 \} \quad (5)$$

2. Perform Arnold transform to scramble the watermark image and get scrambled image.
3. Divide each pixel of watermark image by 100.
4. Convert two-dimensional image matrix into a one-dimensional vector W of length $M1 \times M2$.

$$W = \{ W(i) = \text{Image}(k,j), 0 \leq i < M1 \times M2 , 0 \leq k < M1, \quad 0 \leq j < M2 \} \quad (6)$$

5. Convert the audio file into audio samples.
6. Apply FFT to the original host signal and segmented the FFT signal into non-overlapping subsections.
7. Calculate the magnitude and phase spectrum of each subsection using Fast Fourier Transform (FFT).
8. Energy of each subsection is then calculated using the following equation;

$$E = \sum_i |v(i)|^2 \quad (7)$$

9. The watermark is then embedded into the highest N peaks of the highest energy segments by using the equation (1) shown in [8], where N is the length of one dimensional vector of image.
10. Inverse Fast Fourier Transform (IFFT) is then applied to FFT domain in order to obtain the watermarked audio signal.

4.2. Watermark Extraction Procedure

The extraction process is implemented by using the following steps:

1. The watermarked audio signal is transformed into FFT domain.
2. Extract the highest prominent peaks from the FFT coefficients which are located at the same position in the embedding process above.
3. The watermark vector is then calculated by performing the extraction algorithm using the inverse operation of (1) represented by equation (2).
4. Multiply each element of watermark vector by 100.
5. Convert extracted watermarked vector into two dimensional matrix which represents scrambled image.
6. Apply Anti-Arnold transform to get the original watermark image.

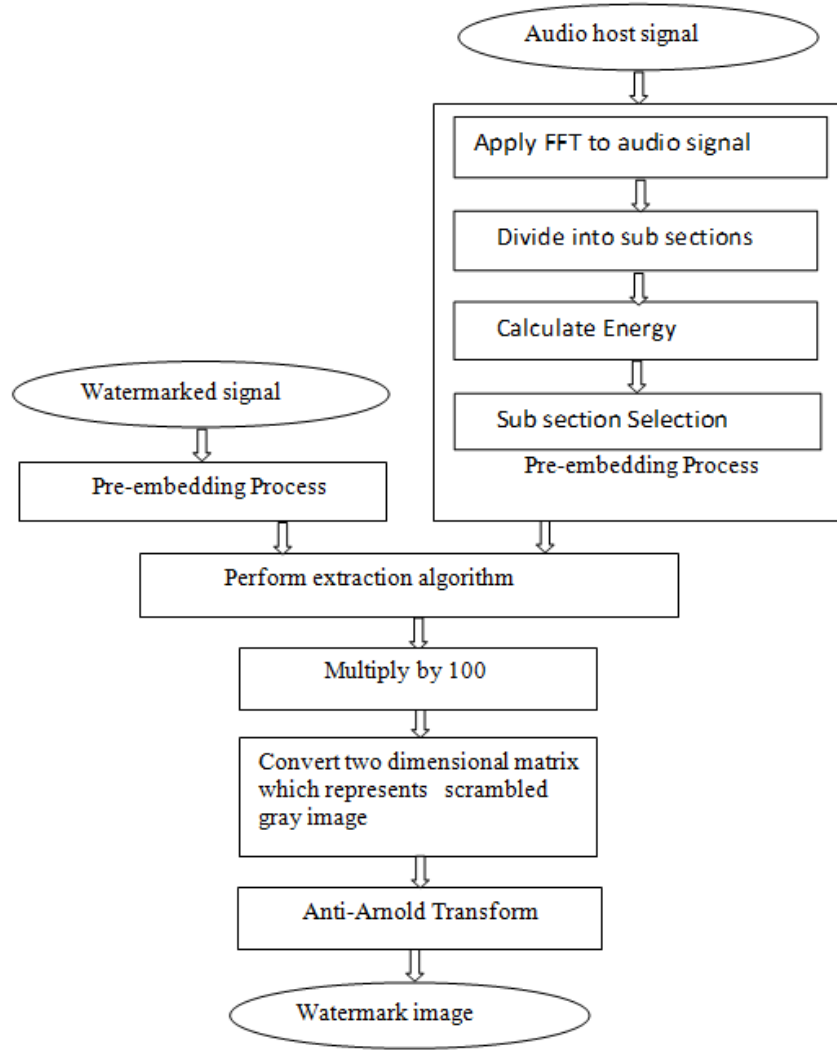


Figure 2. Watermark Extraction Process

5. Performance Evaluation Framework

In this section, we introduce performance evaluation of our proposed system

5.1. Similarity (SIM)

In order to evaluate the performance of the proposed method, the correlation coefficient between the original watermark X and the extracted watermark X^* is calculated by using the following similarity $SIM(X, X^*)$ formula:

$$SIM(X, X^*) = \frac{X \cdot X^*}{\sqrt{X \cdot X^*}} \quad (8)$$

It is highly unlikely that X^* will be identical to X . To decide whether X and X^* match, we determine whether the $SIM(X, X^*) > T$, where T is a detection threshold. In this study, the selected detection threshold (T) value is 6 [8].

5.2. Perceptual Quality

Perceptual quality refers to the imperceptibility of embedded watermark data within the host signal. In most applications it is important that the watermark is undetectable to a listener or a viewer. This ensures that the quality of the host signal is not perceivably distorted and does not indicate the presence or location of a watermark. In this paper, the signal-to-noise ratio (SNR) of the watermarked signal versus the host signal was used as a quality measure. In order to evaluate the quality of watermarked signal, the following signal-to-noise ratio (SNR) equation is used.

$$SNR = 10 \log_{10} \left\{ \frac{\sum_{n=1}^N S^2(n)}{\sum_{n=1}^N [S(n) - S'(n)]^2} \right\} \quad (9)$$

where $S(n)$ is a host audio signal of length N samples and $S'(n)$ be watermarked audio signal.

5.3. Subjective Quality Evaluation

The inaudibility of our watermarking method has been done by listening tests involving ten persons. Each listener was presented with the pairs of original signal and the watermarked signal and was asked to report whether any difference could be detected between the two signals. The ten people listened to each pair for 10 times and they have a grade for this pair, using the ITU-R BS.1284 standardized 5-point grading scale. The average grade for of each pair from all listeners is the final grade for this pair.

Table 1. Grading Scale (ITU-R)

Grade	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very Annoying

6. Experimental Results

In this section, we evaluate the performance of our watermarking system for four different types of 16 bit mono audio signals sampled at 44.1 kHz: (a) an instrumental song ‘Hey Jude’ played by a Korean traditional musical instrument called the gayageum; (b) the song ‘Let it Be’ by the Beatles; (c) the beginning of Symphony No. 5 in C minor, Op.67, by Ludwig van Beethoven; (d) a human voice providing TOEIC (Test of English for International Communication) listening test instruction. A gray-scale image shown in figure 3 was used as watermark for embedding in the audio files. We choose 15×15 gray-scale image as watermark image. The size of the watermark image was chosen after taking into consideration the length of the audio files



Figure 3. The Original Watermark Image

Performance of audio watermarking algorithm is commonly evaluated with respect to two common metrics: (a) Imperceptibility (Inaudibility) and (b) Robustness.

6.1. Imperceptibility Test

Imperceptibility is related to the perceptual quality of the watermarked signal. It ensures that the quality of the signal is not perceptible to a listener. To measure imperceptibility, we use Signal-to-Noise ratio (SNR) as an objective measure and a listening test as a subjective measure.

Table 2. SNR and Average ITU-R Grade Value of the Proposed Watermarking System

Type of Signal	Signal-to-Noise ratio (SNR)			Average Grade(ITU-R)
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$	
Hey Jude	42.53	36.51	33	5.0
Let it be	44.22	38.20	34.68	5.0
Symphony No 5	44.92	38.90	35.38	5.0
Human Voice	45.35	39.33	35.80	5.0

6.2. Robustness Test

The robustness of a watermarking method is defined as the ability of watermark detector to extract the embedded watermark after common signal processing operations and attacks. In this paper, robustness is measured in terms of Similarity (SIM).

Table 3. Similarity (SIM) of the Proposed Method without Attack

Type of Signal	Similarity (SIM)		
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$
Hey Jude	16.02	16.02	16.02
Let it be	16.02	16.02	16.02
Symphony No 5	16.02	16.02	16.02
Human Voice	16.02	16.02	16.02

Table 4. Similarity (SIM) of the Proposed Method against Re-sampling

Type of Signal	Similarity (SIM)		
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$
Hey Jude	15.97	15.99	15.99
Let it be	16	16	16
Symphony No 5	16	16	16
Human Voice	16	16	16

Table 5. Similarity (SIM) of the Proposed Method against Re-quantization

Type of Signal	Similarity (SIM)		
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$
Hey Jude	16	16	15.98
Let it be	15.97	15.98	16
Symphony No 5	15.58	15.94	16
Human Voice	15.14	15.05	14.98

Table 6. Similarity (SIM) of the Proposed Method against Filter Attacks

Type of Signal	Similarity (SIM)		
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$
Hey Jude	15.39	15.70	15.81
Let it be	15.37	15.69	15.80
Symphony No 5	15.68	15.84	15.90
Human Voice	15.93	15.97	15.98

Table 7. Similarity (SIM) of the Proposed Method against Random Noise

Type of Signal	Similarity (SIM)		
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$
Hey Jude	15	15.53	15.73
Let it be	16	15.91	16
Symphony No 5	15.75	16	16
Human Voice	15.58	15.97	16

Table 8. Similarity (SIM) of the Proposed Method against AWGN

Type of Signal	Similarity (SIM)		
	$\alpha = 0.01$	$\alpha = 0.02$	$\alpha = 0.03$
Hey Jude	16	16	16
Let it be	16	16	16
Symphony No 5	15.91	15.96	15.98
Human Voice	15.79	15.90	15.94

7. Conclusions

In this paper, we have presented a new watermarking method using Fast Fourier Transform (FFT) for copyright protection of audio sound. Experimental results indicate that our proposed watermarking system has compromised audibility and robustness better. This method also shows strong robustness against several kinds of attacks such as noise addition, re-sampling, re-quantization, filtering etc. These results demonstrate that our proposed watermarking method can be suitable candidate for audio copyright protection.

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