Geometric Invariant Audio Watermarking

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***Abstract*—Watermarking is a technique, which is used in protecting digital information like images, videos and audio as it provides copyrights and ownership. Audio watermarking is more challenging than image watermarking due to the dynamic supremacy of hearing capacity over the visual field. To develop a geometric invariant audio watermarking scheme without degrading acoustical quality is more challenging. This thesis proposes a spread-spectrum audio watermarking scheme based on a geometric invariant feature. The watermark embedding is actually performed in the Discrete Fourier Transform domain. The various audio signal distortions like pitch-shifting, random cropping, Time scale modifications, etc are proposed to analyze in this paper. The proposed method uses average Fourier magnitude over log-coordinate, which can resist most of the audio signal distortions. Through experiments we try to demonstrate that average Fourier magnitude over log-coordinate is an appropriate embedding region for robust audio watermarking. Inverse Fourier Transform is used to retrieve the embedded watermark. MATLAB 7.8 (version 2009a) is used to implement the algorithms discussed in this thesis. The proposed algorithm may work as a tool for securing intellectual properties of the musicians and audio distribution companies because of its high robustness and imperceptibility.**

Keywords—Audio watermarking, geometric invariance, log coordinate mapping (LCM) feature, pitch shifting, time-scaling modification (TSM) Discrete Cosine Transform(DCT).

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I. INTRODUCTION

The digital data can be processed, accessed, and it can be transmitted very quickly using networks. There are numerous technical, legal, and organizational problems which arise when there is wide scale use of digital documents. Digital information can be copied any number of times from one medium to another; they can be transmitted through networks, etc., all without compromising the quality of the data. There is no way to distinguish between an original electronic documents and its copy. It is easy to change any part of an un protected electronic document. One possibility here is to replace original signatures with cryptographic methods. Digital signature is data items formed by the signatory and created from the document that is to be signed. It relates the documents to the signatory in a secure and reliable way. Digital watermarking has been proposed as one way to accomplish this. Also advanced Internet services enabled the users to create copy and distribute multimedia products such as audio, video, and still images with much ease and less effort, minimum or no cost, and in less time. Though it encouraged trading on the Internet, but on the other hand it has created the problem of illegal copying or copyright infringement. Thus, protection of digital rights assumed a primary importance in the digital age.

Digital watermarking can be defined as the process of embedding a certain piece of information (technically known as watermark) into multimedia content including text documents, images, audio or video streams, such that the watermark can be detected or extracted later to make an assertion about the data. The most important properties of digital watermarking techniques are transparency, robustness, security, capacity, invertibility (reversibility) and complexity and possibility of verification. Based on these parameters the algorithms can be evaluated.

- Perceptual transparency - In most of the applications, the watermark-embedding algorithm has to insert additional data without affecting the perceptual quality of the audio host signal. A transparent watermark causes no artifacts or quality loss. Relates to the properties of the human sensory.
- Robustness - Describes whether the watermark can be reliably detected after media operations. It is important to note that robustness does not include attacks on the embedding scheme that are based on the knowledge of the embedding algorithm or on the availability of the detector function. Robustness means resistance to “blind”, non-targeted modifications, or common media operations.
- Security - Describes whether the embedded watermarking information cannot be removed beyond reliable detection by targeted attacks based on a full knowledge of the embedding algorithm and the detector, except the key, and the knowledge of at least one watermarked data. The watermark should prevent unauthorized detection and removal, unless the quality of audio becomes very poor The security aspect also includes the false positive detection rates.
- Capacity - Describes how many information bits can be embedded. It addresses also the possibility of embedding multiple watermarks in one document in parallel.
- Invertibility - Describes the possibility to produce the original data during the watermark retrieval.

- Complexity - Describes the effort and time we need to embed and retrieve a watermark. This parameter is essential if we have real time applications. Another aspect addresses whether the original data in the retrieval process or not. We need to distinguish between non-blind and blind watermarking schemes.

A. Scope of research

Digital watermarking is considered as an imperceptible, robust and secure communication of data related to the host signal, which includes embedding into and extraction from the host signal. The basic goal is that embedded watermark information follows the watermarked multimedia and endures unintentional modifications and intentional removal attempts. This thesis is mainly appropriate for protecting intellectual property rights in all kinds of organization and institution. Digital watermarking have wide ranging applications. Some of the applications are listed below.

1) Ownership Protection: In the ownership protection applications, a watermark containing ownership information is embedded to the multimedia host signal. The watermark, known only to the copyright holder, is expected to be very robust and secure (i.e., to survive common signal processing modifications and intentional attacks), enabling the owner to demonstrate the presence of this watermark in case of dispute to demonstrate his ownership. Ownership protection applications require a small embedding capacity of the system, because the number of bits that can be embedded and extracted with a small probability of error does not have to be large.

2) Authentication and tampering detection: In the content authentication applications, a set of secondary data is embedded in the host multimedia signal and is later used to determine whether the host signal was tampered. The robustness against removing the watermark or making it undetectable is not a concern as there is no such motivation from attacker's point of view. However, forging a valid authentication watermark in an unauthorized or tampered host signal must be prevented. The watermark embedding capacity has to be high to satisfy the need for more additional data than in ownership protection applications.

3) Copy control and access control: In the copy control application, the embedded watermark represents a certain copy control or access control policy. A watermark detector is usually integrated in a recording or playback system. After a watermark has been detected and content decoded, the copy control or access control policy is enforced by directing particular hardware or software operations such as enabling or disabling the record module. These applications require watermarking algorithms resistant against intentional attacks and signal processing modifications.

4) Airline traffic monitoring: Watermarking is used in air traffic monitoring. The pilot communicates with a ground monitoring system through voice at a particular frequency. However, it can be easily trapped and attacked, and is one of the causes of miss communication. To avoid such problems, the flight number is embedded into the voice communication between the ground operator and the flight pilot. As the flight numbers are unique the tracking of flights will become more secure and easy.

B. Objective

The basic idea behind this thesis is to obtain an audio watermarking technique that is invariant against geometric distortions, like time-scale modification (TSM), pitch shifting, random cropping, etc. There are various methods to watermark an audio, aiming to solve the geometric distortion. The thesis focuses on a robust audio watermarking scheme based on the geometric invariant feature. The average Fourier magnitude (AFM) over the log coordinate is invariant to those geometric distortions. This thesis proposes a spread-spectrum audio watermarking scheme based on a geometric invariant feature. The watermark is embedded in the geometric invariant feature, that is the embedding is actually performed in the DFT domain. The watermarked audio achieves high auditory quality in both objective and subjective quality assessments.

C. Organization

The central idea of this thesis is to propose an audio watermarking scheme, which is resilient against most of the geometric distortions.

In Section II, a detailed literature survey will be provided. The details of different Audio watermarking techniques are explained. Section III deals with problem formulation and details of the underlined concept. The Log coordinate transform, watermark embedding algorithm and its extraction, methods for analyzing the method are explained in detail. Section IV, provides the details of the work that is done so far and the concerning results that are obtained.

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II. LITERATURE SURVEY

The term "digital watermark" was first coined in 1992 by Andrew Tirkel and Charles Osborne Actually, the term used by Tirkel and Osborne was originally used in Japan- from the Japanese-- "denshi sukashi" -- literally, an "electronic watermark". There were many studies done for watermarking images, sounds, text, etc, on the other hand, a few methods for watermarking computer programs have been propose

Several algorithms for embedding and extraction of watermarks in audio sequences have been presented in the past few years. Most of the researches on audio watermarking are based on two basic approaches.

- Temporal watermarking (time domain approach).
- Spectral watermarking (frequency domain approach).

The temporal watermarking hides watermarks directly into digital audio signals in the time domain. The spectral watermarking applies certain frequency transform, such as FFT, DCT, DWT, etc, to the audio signal, and hides the watermark information into the transformed data block. In general, the time domain techniques provide least robustness as a simple low pass filtering can remove the watermark. Hence time domain techniques are not advisable for the applications such as copyright protection and airline traffic monitoring; however, it can be used in applications like proving ownership and medical applications.

One of the popular method of audio watermarking is the spread-spectrum watermarking scheme that can be used in both the approaches. Spread spectrum watermarking is a correlation method which embeds weighted pseudo-random sequence to the audio and detects watermark by calculating correlation between pseudo-random noise sequence and watermarked audio signal. This method is easy to implement, but has some serious disadvantages: it requires time-consuming psycho-acoustic shaping to reduce audible noise, and susceptible to time-scale modification attack. All of the developed algorithms take advantage of the perceptual properties of the human auditory system (HAS) in order to add a watermark into a host signal in a perceptually transparent manner. Embedding additional information into audio sequences is a more tedious task than in the case of images, due to the dynamic supremacy of the HAS over the human visual system. Human ear can perceive the power range greater than 10^9:1 and range frequencies of 10^3:1[11]. In addition, human ear can hear the low ambient Gaussian noise in the order of 70dB [11]. However, there are some useful features such as the louder sounds mask the corresponding slow sounds. This feature can be used to embed additional information like a watermark. Further, HAS is insensitive to a constant relative phase shift in a stationary audio signal, and, some spectral distortions are interpreted as natural, perceptually non-annoying ones. There are three main issues for the design of a watermarking system.

- ISSUE 1: Design of a watermark signal W to be added to the host signal. Typically, the watermark signal depends on a key K and watermark information I into which it is embedded.

$$W=f_0(I,K) \quad (1)$$

- ISSUE 2: Design of an embedding method itself that incorporates the watermark signal W into the host data X yielding watermarked data Y.

$$Y=f_1(X,W) \quad (2)$$

- ISSUE 3: Design of a corresponding extraction method that recovers the watermark information from the signal mixture using the key and with help of the original data.

$$\hat{I}=g(X,Y,K) \quad (3)$$

or without the original data,

$$\hat{I}=g(Y,K) \quad (4)$$

The first two issues, watermark signal design and watermark signal embedding, are often regarded as one, especially when the embedded watermark is adaptive to the host signal. Digital watermarking is a technique by which copyright information is embedded into the host signal in a way that the embedded information is imperceptible, and robust against intentional and unintentional attacks. The technique consists of two blocks:

The embedding block, shown in Figure 1, consists of watermark, original signal (or cover object), and watermarking key as the inputs. It creates the embedded signal or watermarked data. Whereas, the inputs for the extraction block is embedded object, key and sometimes watermark as illustrated in Figure 2.

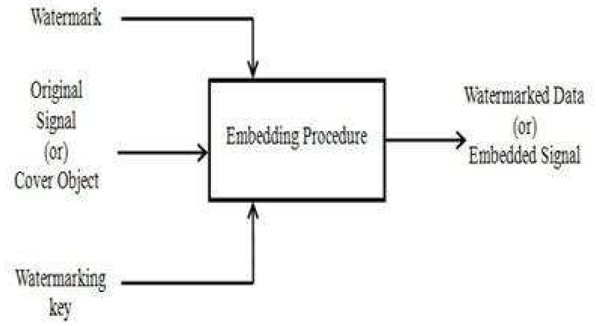

Fig. 1. Watermark Embedding.

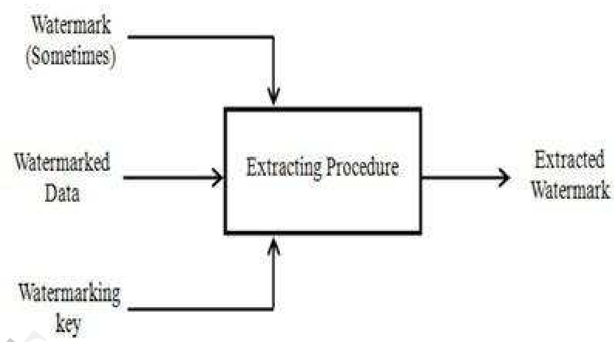

Fig. 2. Watermark Extraction.

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A. Common audio watermarking algorithms

In the following, typical watermarking strategies such as LSB coding, spread spectrum technique, patchwork technique, and quantization index modulation (QIM) are presented.

1) *LSB Coding:* This technique is one of the common techniques employed in signal processing applications. It is based on the substitution of the LSB of the carrier signal with the bit pattern from the watermark noise [12]. The robustness depends on the number of bits that are being replaced in the host signal.To change the default, adjust the template as follows.

2) *Spread Spectrum Technique :* These techniques are derived from the concepts used in spread spectrum communication [12]. The basic approach is that a narrow band signal is transmitted over the large bandwidth signal which makes them undetectable as the energy of the signal is overlapped. In the similar way the watermark is spread over multiple frequency bins so that the energy in any one bin is very small and certainly undetectable.

3) *Patchwork Technique:* The data to be watermarked is separated into two distinct subsets. One feature of the data is chosen and modified in opposite directions in both subsets [12]. For an example let the original signal is divided into two parts A and B, then the part A is increased by a fraction Δ and the part B is decreased by some amount Δ. The samples separation is the secret key which is termed

as watermarking key. Detection of watermark is done by following the statistical properties of the audio signal.

4) Quantization Index Modulation: The quantization index modulation (QIM) is a technique which uses quantization of samples to embed watermark. The basic principle of QIM is to find the maximum value of the samples and to divide the range 0 to the maximum value into intervals of step size Δ. The intervals are assigned a value of 0 or 1 depending on any pseudo random sequence. Each sample has quantized value, thus, a polarity is assigned based on the location of the interval. The watermark is embedded by changing the value of the median for created interval and by the similarity of the polarity and watermark bit.

There have been some works aiming to solve the geometric distortion or synchronization problem. Kirovski *et al.*[4] applied redundant-chip coding to spread-spectrum watermarking. Only the central sample of each expanded chip was detected and used for computing the correlation. The method can resist geometric distortion such as time scaling and frequency scaling. Note that multiple searching may increase the false detection rate. Mansour *et al.*[7] proposed changing the relative length of the middle segments between two successive peaks of the smoothed waveform to embed a TSM-invariant watermark. However, watermark detection depends to a great extent on the selection of threshold and the robustness against pitch shifting was not reported. Li *et al.*[6] proposed an algorithm based on embedding the watermark in the perceptually important localized regions, that is the rhythm. The algorithm is robust against pitch invariant TSM. However, it only works well on audio with an obvious rhythm and is not robust against pitch shifting.

Xiang *et al.*[2] found that the relative relation in the number of samples among different bins in the audio histogram and audio mean were robust against TSM attacks. A robust audio watermarking algorithm based on these two statistical features was proposed by using the histogram specification. The watermark is robust against random cropping as well as pitch invariant TSM and resample TSM. But it is not robust enough for MP3 compression at low data rates, and the embedded watermark is easy to be removed by manipulating the histogram. In [13], authors propose a watermarking system in cepstrum domain 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 cepstral coefficients and the frequency masking characteristics of human auditory system. In Cox's method [14], watermarks are embedded into the highest m-DCT coefficient of the whole sound excluding the DC component by the following equation:

$$v_i' = v_i(1+\alpha x_i) \quad (5)$$

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, and v_i' is an adjusted magnitude coefficient. The watermark sequence is extracted by performing the inverse operation represented by the following equation:

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III. Proposed Method

Globalization and internet are the main reasons for the growth of research and sharing of information. However, they have become the greatest tool for malicious user to attack and pirate the digital media. The ease of content modification and a perfect reproduction in digital domain have promoted the protection of intellectual ownership and the prevention of the unauthorized tampering of multimedia data to become an important technological and research issue. Digital watermarking has been proposed as a new method to enforce the intellectual property rights, tracing of illegal copies of digital media and protect digital media from tampering. Several audio watermarking schemes have been presented over the years. The development of a geometric invariant audio watermarking scheme without degrading acoustical quality is challenging work. The thesis proposes a geometric invariant feature, the average Fourier magnitude (AFM) over the log coordinate, which is invariant to geometric distortions and is denoted by log coordinate mapping (LCM) feature. The LCM feature is very robust to audio geometric distortions, such as time-scale modifications (TSM), tempo invariant pitch shifting, random cropping etc.

A. Log Coordinate Transform on Frequency Index

Geometric distortions can be described in the frequency domain as follows:

$$f' = \beta . f \quad (6)$$

Where β stands for the frequency scaling factor, f and f' are a frequency point of the original audio and the corresponding frequency point of a distorted audio, respectively. Frequency scaling by β can be converted into shifting by logβ in the log coordinates. Taking the logarithm of (6), it can be rewritten as follows:

$$\log_b f' = \log_b \beta + \log_b f \quad (7)$$

Thus geometric distortions can be easily manipulated in the log coordinate of frequency index. As amplitude scaling is unavoidable during attacks, we select a correlation based watermarking which can resist amplitude scaling. The host feature is the average Fourier magnitude (AFM) over the Log coordinate frequency index. Given a signal, s(n) = [s_1.....s_N] we perform a DFT and get the Fourier magnitude *S(f)*. After selecting a portion of the normalized frequency indexes, we perform a log coordinate transform on frequency index as shown in

$$l = floor(\log_b(f/R)) + L/2 \quad (8)$$

$$R = \sqrt{2}.f_m$$

$$b = 2^{1/L}$$

where L is the number of log intervals and is specified by users. The selected frequency index f is mapped to discrete log

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coordinates l $(0 \leq l < L)$, so that the selected frequency coefficient $S(f)$ is mapped to a log coordinate mapping feature $a(l)$ which is defined as follows.

$$a(l)=1/(f_2-f_1) \int S(f)df \quad (9)$$

$$f_1=\min \{f \mid floor(\log_b(f/R))+L/2=l\}$$
$$f_2=\max \{f \mid floor(\log_b(f/R))+L/2=l\}$$

B. Watermark Embedding

Watermark (W_i) is a direct sequence spread-spectrum (DSSS) encoded with N_P bit bipolar PN sequence. The hidden data W consists of spread-spectrum information watermark (W_i) and a tracking sequence T generated by a key. Apply DFT on the original audio signal s(n) and obtain the Fourier magnitude $S(f)$ and the phase. Performing a discrete log-coordinate transform to a portion of the normalized frequency indexes f's, we obtain the discrete log-coordinate l.

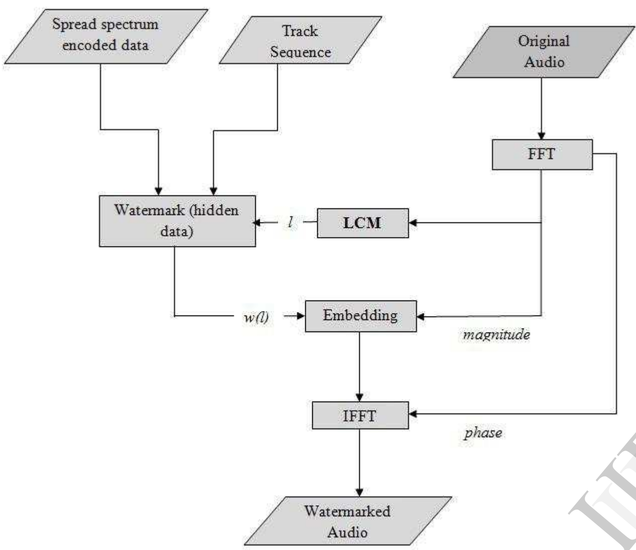

Fig. 3. Proposed Watermark Embedding procedure.

Here several DFT magnitude coefficients are mapped to one LCM feature. One watermark bit w(l) is embedded into several DFT magnitude coefficients which are mapped to one LCM feature. Modify the Fourier magnitude $S(f)$ to embed the hidden bit $w(l)$ according to

$$\hat{S}(f)=S(f)\times(1+\alpha.w(l)) \quad (10)$$

where $S(f),\hat{S}(f)$ are the Fourier magnitude coefficients before and after embedding, and α is the embedding strength. Finally, by performing an IDFT to the modified DFT coefficients, the watermarked audio signal ŝ(n) is obtained. It is observed that not the whole range of average Fourier magnitude (AFM) over the log coordinate is suitable for embedding watermarks. The amplitudes near the highest frequency are small, and this part is sensitive to low-pass filtering. So we may set the watermark embedding region to the low and middle frequency components.

C. Watermark Extraction

Watermark is extracted from the average Fourier magnitude over the log coordinate (LCM feature). The LCM feature may get translated after geometric distortion. First, apply the DFT on the watermarked audio signal ŝ(n) and obtain the magnitude coefficient $\hat{S}(f)$. Then perform a discrete log-coordinate transform to the frequency index f and average the entire magnitude $\hat{S}(f)$ with the same discrete log-coordinate l.

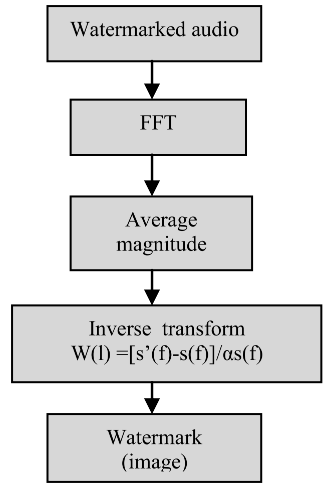

Fig. 4. Proposed Watermark detection procedure.

Computing the W(l) by applying the inverse transform. From we get the data with one row. Arrange it in rows and columns get the watermark image

$$W(l) =[s'(f)-s(f)]/\alpha s(f) \quad (11)$$

D. Effectiveness of log coordinate transform

If we embed the watermark signal in to the Fourier magnitude of audio one to one and same scale, the original watermark will suffer the same distortion as the audio signal. When the synchronization attacks are applied to the watermarked audio, the Fourier magnitude of the audio will fluctuate and the frequency index will be scaled. The case of the watermark is the same. Obviously the original watermark and the survival watermark are not correlative.

The case is different when applying log coordinate transform in watermark embedding and extraction. We apply log coordinate mapping to the watermark index and generate embedding positions in DFT magnitude. Now one watermark bit will be embedded in multiple DFT magnitudes. After attacks there will be some fluctuations in magnitudes, and we perform the average of the Fourier magnitudes. Before watermark extraction we utilize log coordinate transform to retrieve the watermark index. Now the watermark bits can be extracted from the survival watermark signal correctly.

- Under Random Cropping: Random cropping means that a portion of the audio is lost in the time domain, but in the frequency domain, it only introduces tiny fluctuations. To resist random cropping, the watermarking strategy must be global. As the length of audio clip varies after random cropping, the frequency index must be normalised after Fourier transform. Geometric distortion by random cropping can be described by the equation (6). A powerful tool to deal with the scaling factor β is log coordinate transform. A logarithm could convert the scaling into shifting (7) in the logarithm axis.

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- Under Pitch Shifting: Pitch shifting is a very common form of processing used to change the base frequency without changing the tempo. Pitch shifting may be implemented as follows: resample an audio signal for shifting the pitch, then remove and/or insert some samples of the resampled audio signal in the time domain in order to keep the tempo invariant. Removing and inserting some samples cause only a small fluctuation in the frequency domain. Theoretically there exists a statistically positive linear correlation between pitch shifted and original audio (6)
- Under Pitch-Invariant TSM: Pitch-invariant TSM can be considered to be removing and/or inserting some samples of audio signals while preserving the pitch. It causes only a small fluctuation to the LCM feature in the frequency domain.

E. *Methods of Analysis.*

1) Quality of Watermarked Audio: The objective quality is measured by SNR and objective difference grade (ODG). The ODG value is mapped to the following description : 0 (insensitive),1 (audible), 2 (slightly annoying), 3 (annoying), 4 (very annoying), and 5 (catastrophic). A subjective quality evaluation of the watermarking method was done by asking 10 persons to listen to the four audio clips. In the first phase of the test, participants were presented with thepairs of the original and the watermarked audio clips in random order and asked to determine which one was the original clip and which one was not. A discrimination rate (the rate of correct discrimination) near to 50% means that the original and watermarked audio clips cannot be discriminated. In the second phase of the test, the persons are presented with the original and watermarked audio objects, and then give scores for each audio. The mean opinion score (MOS) determines the amount of distortion. The five-point impairment scale is applied, 5.0 for imperceptible, 4.0 for perceptible but not annoying, 3.0 for slightly annoying, 2.0 for annoying, and 1.0 for very annoying.

2) Robustness Tests: To evaluate the robustness performance of the proposed algorithm, we apply tests defined by the Secure Digital Music Initiative (SDMI) industry committee.

IV. CONCLUTIONS

In this paper, we propose a robust audio watermarking scheme based on the geometric invariant LCM feature. This paper proposes an audio watermark embedding strategy, which is actually performed in DFT domain. The watermark is embedded in the LCM feature but is actually embedded in the Fourier coefficients which are mapped to the feature via the LCM. The watermarked audio achieves high auditory quality in both objective and subjective quality assessments. A mixed correlation between the LCM feature and a key-generated PN tracking sequence is proposed to align the log-coordinate mapping, thus synchronizing the audio watermark efficiently with only one FFT and one IFFT. Extensive experiments and theoretical analysis shows that the LCM feature is very robust to kinds of audio geometric distortions such as cropping, resample TSM, pitch-invariant TSM, tempo-invariant pitch shifting, etc. We considered audio clips, which are in '.WAV' format, mono, 16 bits/sample, 20s, and 44.1-kHz sampling frequency. We choose the length of watermark I=64 bits, the length of tracking sequence N_T=320, and a total L=960 bits of hidden data are embedded. We adopt the length of DFT and IDFT being equal to the length of the host audio clip.

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