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Audio Watermarking: A Critical Review

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Abstract— The proliferation of digital audio file is costing loss of revenue to the owner of copyright information especially in the music industry. The paper brings to view works done by various on digital audio watermarking and using discrete wavelet transform (DWT) and discrete cosine transform (DCT) with chaotic watermarking towards carrying out investigation for real life application.

Index Terms— Audio watermarking, chaotic watermarking, DWT, DCT.

1 INTRODUCTION

DIGITAL watermarking has to do with embedding pieces of information into a digital media for protecting it against copyright infringements and other unauthorized applications.

Digital audio watermarking has to do with protecting digital audio file against illegal copying. A lot of works has been done on digital watermarking of various media such as image and video, but this particular review will focus on digital watermarking of audio file to examine if real life commercial implementation is possible out of various techniques that has been proposed by different authors. Digital Audio files are particularly the most abused for copyright infringements because they can be downloaded and copied with ease. Thus the owner of the works is at loss in terms of revenue. A lot of recent works have proposed solutions to this problem of copyright infringement. Some involves the use of various types of watermarks. Some authors proposed the use of text or images to be embedded imperceptibly in the audio file such that any of such audio file could be analyzed for possible recovery. Some other authors use pseudorandom number generators for watermark generation while some use chaotic watermarks for protection of audio files combined with various techniques and methodology. So far, despite numerous techniques and methodologies being rolled out for digital audio file copyright protection, the success recorded for real life application has been low. To show the need for copyright protection of digital audio file as being the most abused, The New York Times(International Herald Tribune) of 19th of July,2011 reported that Chinese Biggest Search Engine, known for illegal downloads makes music deal that the company will pay a fee each time songs are downloaded or streamed. The search engine 'Baidu' as reported by Dan Levin announced a major licensing with three of the largest music companies that would allow Chinese web user to legally download and stream hundreds of thousands of songs free. The agreement between Baidu and One-stop China, a joint venture between the Universal Music Group, the Warner Music Group and Sony BMG will shut down access to vast amount of pirated music and promises to broadly reshape the way 450 million web users gain access to music online. About 500,000 songs will be licensed and stored on Baidu's server. The paper reported 99% of online music is illegal. In Nigeria, the Senate also has just amended the copyright act in the country making copying and other form of manipulation done on music illegal.

There is therefore the need for a way or technique for protecting this works against abuse, creating a need for critically reviewing the work done so far to know how it can meet this need at the earliest time. This paper will make a review of the of current digital watermarking technique against the various properties of the watermark they satisfy so as to approximately exact the best solution to tackle the factors militating against the real life implementation of the technology in digital audio watermarking. There are about five properties that need to be satisfied for effective application of watermarking technology. These are robustness, imperceptibility, bit rate, security and computational complexity. A discovery of methodology to satisfy these constraints will lead to a way of protecting digital audio which is the aim of this paper.

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2 LITERATURE REVIEW

Research in audio watermarking is not as mature, compared to research in image and video watermarking due to the fact that the human auditory system is much more sensitive than the human visual system and that inaudibility is much more difficult to achieve than invisibility for images (Arnold, et al, 2003). Furthermore, audio signals are represented by much less samples per time interval, which indicates that the amount of information capacity that can be embedded robustly and inaudibly in audio files is much lower than the amount of information that can be embedded in visual files.

Work done on the digital audio watermarking includes the ways of evaluating various algorithms. An algorithm-independent framework for comparing digital watermarking algorithm with respect to bit rate, perceptual quality, computational complexity, and robustness to signal processing was proposed (Gordy et al, 2000). The requirements for practical applications vary, so one criterion may be more important in some situation than the other. Low computation may be required for implementation in real life. Some of the watermark properties are discussed below.

2.1 Bit rate

This is the amount of watermark data that may be Reliably embedded within the host signal per unit time or space. A higher bit rate may be desirable in some application to embed copyright information. Reliability is measured using BER (bit error rate).

$$BER = \frac{100}{B}\sum_{n=0}^{B-1} \begin{cases} 1 & \bar{w}(n) \neq w(n) \\ 0 & \bar{w}(n) = w(n) \end{cases}$$

(1)

$\bar{w}(n)$ =extracted watermark, $\bar{x}(n)$ =host signal of length N

$w(n)$=watermark, $x(n)$=watermarked signal, B= $\frac{N}{M}$ blocks of M samples

2.2 Perceptual quality

This refers to imperceptibility of embedded watermark within the host signal. The signal-to-noise ratio of the watermark versus the host signal is quality measure:

$$SNR = 10\log_{10} \left\{ \frac{\sum_{n=0}^{N-1} x^2(n)}{\sum_{n=0}^{N-1}[\bar{x}(n)-x(n)]^2} \right\} \qquad (2)$$

2.3 Computational complexity

This refers to the processing required to embed data into the host signal and or to extract data from the signal.

2.4 Robustness to signal processing

Digital signal may undergo common signal processing operations such as Linear filtering, sample re-quantisation, D/A(digital-analogue) and A/D(analogue-digital) conversion and lossy compression

2.5 Watermark security

Watermark security refers to the inability by unauthorized users to have access to the raw watermarking channel. In other words, watermark security refers to the inability of unauthorized users to remove, detect and estimate, write or modify the raw watermarking bits. The security of watermarking relies in the secrecy of the keys and only the knowledge of both the algorithm and the keys can break the algorithm (Tom, 2002).

Based on four properties, bit-rate, perceptual quality, computational complexity and robustness to signal processing, five algorithm for public watermarks were compared because of interest in practical applications (Gordy, et al, 2000). These are echo coding, phase coding, DSSS (direct sequence spread spectrum), FHSS (frequency hoped spread spectrum) and frequency masking. For bit rate the frequency masking offer the lowest bit rate. For perceptual quality, echo coding, phase coding and frequency masking introduced most distortion into the audio signal. DSSS and FHSS have a higher SNR due to the fact that the power of the noise-like watermark signal introduced had to be maintained at a very low level. For computational complexity, FHSS, DSSS and Echo coding extraction takes longer than embedding indicating algorithms may run in real-time platform. Frequency masking embedding was the most expensive operation because of the need to compute a complex, time-varying perceptual masking analysis on the host signal. For robustness to signal processing, purely time domain algorithms, echo coding and DSSS, performed poorly, but frequency domain algorithms, phase coding, FHSS and frequency masking produce the best performance. Frequency domain approaches to watermarking are costly to implement than purely-time domain techniques, but have a higher bit rate and more robust watermark extraction under signal processing.

Evaluation of watermarking attacks on audio watermarks indicated the need for more research to improve the quality of existing watermarking method that can be used with electronic commerce applications (Martins, et a, 2001). This work focused on audio attacks likely to be faced for radio transmission of audio files. It tested their attacks on four algorithms including PCM (pulse code modulation) watermarking algorithm still under development. The outcome for the PCM watermarking was that zero-cross inserts change and remove of all watermarks while re-sampling destroys the watermark completely.

A general description of digital watermarking algorithm and its applications in general was given by (Christine, et al, 2001). General watermarking problems, drawing parallels to communication and information theory to help understand the fundamental properties and of limitations of watermarking system, were reviewed. Many technical problems associated with watermarking yet to be solved and whether it can be used in court of law was addressed. Questions, such as what are reasonable distortions allowable, what measure of distortion can be used to determine the effectiveness of an algorithm and so on, were raised.

On addressing the usual implicit assumption that digital watermarking has as its main target copyright and copy protection application and taking a look at the term 'security' properties of watermarks, it was concluded that the likelihood of a military grade secure watermarking algorithm does not exist(Ton,2002)

The paper focused on the design of a content-fragile audio watermarking scheme to allow several post production processes and on the design of an invertible watermarking scheme combined with digital signatures for high security application (Martin, et al, 2003).

A survey of audio watermarking techniques noted that for sensitivity of human ear the design of good audio watermarking schemes are not easy to design and that current watermarking techniques are far from being perfect (Hyoung, 2004). Table 1 below shows the characteristics of the algorithm considered.

An overview of watermarking schemes based on chaotic generators and correlation detector presented a transform domain technique involving multiplicative embedding of high-frequency chaotic watermarks in low frequencies of the discrete fourier transform (DFT)(Anastasios,2004). High pass chaotic watermarks prove to perform better white ones whereas low pass watermark have the worst performance when no distortion is influenced on the watermarked signal.

TABLE 1: COMPARISON OF VARIOUS WATERMARKING TECHNIQUES.

Techniques	**Advantages**	**Disadvantages**
Spread spectrum	Easy to implement	It requires time consuming psycho acoustic shaping to reduce audible noise, susceptible to time-scale modification attacks and difficulty in synchronization
Quantization	Easy to implement and robust against noise to a particular threshold	Not robust against attacks
Two set	-	-
Replica method	Immunity to synchronization attacks	-
Echo hiding	imperceptibility	High complexity due to ceptrum or autoceptrum computation during detection and echo can be detected without prior knowledge.

On comparison of watermarks generated by three well known chaotic functions, logistic map performed well if not better than skew tent and Bernoulli maps in the presence of applied attacks (Aidan, 2005).

Two (2-D Arnold cat) chaotic maps to improve security, one map to encrypt the position of the host image, and another map to determine the pixel bit of the host image for watermark embedding was introduced(Xianyoung, et al,2007). It claims to be imperceptible in case of watermark and it is also robust to some typical signal processing operations.

A comparison between watermarks generated from chaotic functions and pseudorandom number sequences showed that chaotic watermarks offer superior performance over the pseudo random based watermarks with low pass chaotic signals having the best overall performance for the various attack discussed(Aidan, et al,2007).

A new watermarking model combining a joint-time frequency(TF) representation using molecular matching pursuit(MMP) algorithm and a psychoacoustic model was introduced(Mathieu, et al,2008). This model achieved (claim) imperceptibility and robustness to common signal processing operation but falters for low pass filter and audibility depends on type of music.

The use of chaotic function in watermark generation showed that chaotic sequences have robustness over the widely used pseudorandom sequences in watermarking applications and in particular the watermarks generated by logistic map have superior performance over other chaotic maps used to generate watermarks (Aidan, 2009).

Audio watermarking based on discrete wavelet transform (DWT) and singular value decomposition (SVD) was introduced (Ali, et al, 2010). A binary image of size 6x4 pixel was embedded into audio file. It was reported that the algorithm satisfies the desired feature of optimal audio watermarking which have been set by the International Federation of photography Industry (IFPI). IFPI states that the watermark should not degrade the perception of audio, the algorithm should offer resistance to most common audio processing operations and attacks, and the watermark should prevent unauthorised removal unless the quality of audio becomes very poor.

A blind robust digital watermarking scheme using chaotic encryption and HVS (human visual system) in the DWT domain was presented (Ke-Xin Yin, et al2010). The watermark is encrypted using logistic map.

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A combination of DCT and DWT to audio signal with improved imperceptibility and robustness with improved synchronization scheme was introduced
(Hooman, et al ,2010).

Chaos based watermarking algorithm based on discrete chaotic iteration tested on image produced a robust and efficient algorithm with security using the bitwise exclusive-OR (XOR) was introduced (Christophe, 2010).

3 DISCUSSIONS

The methods used and various the properties they satisfy by authors are shown in Table 2. The appropriate method to fully satisfy the required digital audio watermarking properties will combine of DWT/DCT with chaotic watermarks to increase security and reduce complexity. The implied methodology will embeds chaotic signals combined with an image or logo as watermark in parts of audio data (Aidan, et al (2009) and Ali ,et al (2010).

In recent years, chaotic maps have been used for digital watermark to increase the security. The most attractive features of commonly used one are the logistic map, which is described by:

$$z_n+1 = \mu z_n(1 - z_n) \qquad (3)$$

where $z_n \epsilon (0, 1)$, $\mu \epsilon (0, 4)$. When $\mu > 3.5699456$, the sequence iterated with initial value z0 is chaotic, different sequences will be generated with different initial values. The sequence is normally distributed in the interval of (0, 1) and is non-periodic, therefore the interval of (0, 1) can be divided into several subintervals which correspond to different pixel bits for watermark embedding.

For security reasons, the watermark can be mixed before its embedding. A common way to achieve this stage is to use the bitwise exclusive or (XOR), for example, between the watermark and a logistic map. A mixture scheme based on chaotic iterations is suggested. The discrete cosine transforms (DCT) and the discrete wavelet transform (DWT) are commonly used for watermarking purpose. Several research works employ the wavelet transform because it presents a number of advantages over the DCT. Due to its excellent spatio-frequency localization properties, the DWT is very suitable to identify areas in an audio signal where a watermark can be embedded effectively. Many DWT-based audio watermarking techniques can be found in the wavelet transform. Many audio watermarking techniques attempt to satisfy watermarking requirements by exploiting the imperfections of the human auditory insensitive to small amplitude changes, either in the time-domain or frequency-domain, to embed watermark information.

TABLE 2: WATERMARK PROPERTIES, TECHNIQUES AND AUTHORS

			Watermark Properties					
Authors	Techniques	Medium	Robustness	Bit rate	Imperceptibility	security	Compl-exity	comments
Xiang et al (2007)	Chaotic(2-dim Arnold Cat Map)	Image	✓	_	✓	Key(private)	_	_
Mathieu et al (2008)	MMP(molecular Matching technique:MDCT/DWT	Audio	✓	_	✓	_	_	Low pass

Ali et al(2010	DWT/SVD	Audio	✓	_	✓	_	_	_
Ke-xin et al(2010)	Chaotic encryption(logistic map) and HVS in DWT	Image	✓	_	✓	_	_	_
Aidan et al(2007)	Chaotic watermarks (low pass)	Image	✓	_	✓	_	_	_
Hooman et al(2010	DWT/DCT	Audio	✓	_	✓	_	_	Improved synchronization
Christophe et al(2010)	Topological chaos(Discrete chaotic Iteration)	Image	✓	_	_	XOR(with Logistic map	_	Efficient

4 CONCLUSIONS AND FUTURE DIRECTION

The use of chaotic function in watermarking has been increasingly investigated and consideration should be given to a real life application to digital audio watermarking. Digital audio watermark technology is an active research area in industry and at the post-graduate level in colleges.
The digital audio watermark has potential to be used as part of an overall system for managing IP rights, and can be used not only to know the author of a particular audio file, but also record the path a particular file takes if it is distributed in an unauthorized manner. The work in progress will embed chaotic signals combined with an image or logo as watermark in parts of audio data. A mixture scheme based on chaotic iteration for improved security will be investigated.

REFERENCES

[1] Aidan M and John G. K (2005): "Generation and Detection of watermarks derived from chaotic functions", Department of Computer Sc, National University of Ireland, Maynooth, co. Kildare, Ireland.

[2] Aidan M, John G. K and Daniel M. Hs (2007): "Performance Analysis of Chaotic and White Watermarks in the presence of common watermark attacks, The Computer Journal Vol.00 No.

[3] Aidan Mooney (2009): "Chaos Based digital watermarking", Department of Computer Sc, National University of Ireland, Maynooth

[4] Ali A and Ahmad M (2010): "Digital Audio Watermarking Based on Discrete Wavelets Transform and Singular Value Decomposition, European Journal of Scientific Research , ISSN 1450-216x vol 36 N1 pp 6-21.

[5] Anastasios T , Nikos N and Ioannis P (2004): "Chaotic watermark sequences for correlation-Based schemes,Deptment of Informatics ,Aristotle University of Thessaloniki, Greece.

[6] Arnold, Schumucker & Wolthusen(2003): " Digital watermarking and content protection: Techniques and applications", Norwood, MA: Artech House, 2003.

[7] Christine .I .P et al (2001): " Digital watermarking: algorithms and Applications", IEEE Signal Processing magazine, 1053-58888,p33-46,july 2001.

[8] Christophe G and Jacques M. B(2010): "A new Chaos – Based Watermarking Algorithm, SECRPT'10, Int conf. On Security and Cryptographiy, Greece.

[9] Gordy J.D and Bruton L.T(2000): 'Perforsmance evaluation of Digital Audio Watermarking Algorithms, Dept. Of Electrical and Computer Engineering, University of Calgary, Alberta, Canada.

[10] Ke-xin Y, Zhang Li-juan Z. W, Xiao-lin Fu and Chang Liu (2010): "Digital watermarking algorithm based on chaotic encryption and HVS.

[11] Hooman Nikmehr et al (2010): "A new approach to Audio Watermarking Using Discrete Wavelet and Cosine Transforms ,1st International Conference on Communication and Engineering, 22-24 Dec 2010,pp 1/183-10/183.

[12] Hyoung J K.( ):" Audio watermarking Techniques", Dept of control and Instrumentation Engineering, kangwo National University, Chunchon 200-201, Korea.

[13] Martin S , Fabien A. P. P, Jana D, Nazim F, Caroline F, Frédéric R and Christian Seibel (2001):" Stirmark Benchmark: Audio watermarking attacks, Conference on Information technology, coding and computing (ITCC 2001), April 2-4,Las Vegas,S.49-54.

[14] Martin S and Jana D.(2003): "Watermarking-Based Digital Audio Data Authentication, EURASIP, Journal on Applied signal processing, Hindari Publishing Corporation,p1001-1015.

[15] Mathieu Parvaix et al(2008):"An audio watermarking method based on molecular matching pursuit", IEEE International conference on acoustics, speech and signal processing ICA SSP ,2008, Las Vegas, Nevada,US

[16] Ton Kalker(2002): "Consideration on watermarking Security", Philips Research Eindhoven, Netherlands.
[17] Xianyong Wu and Zhi-Hong Guan (2007):" A novel digital watermarking algorithm based on chaotic maps", physics letters A(2007) doi:10.1016/j.physlet2007.01.134