NOVEL TECHNIQUES FOR IMPROVING THE PERFORMANCE OF DIGITAL AUDIO WATERMARKING FOR COPYRIGHT PROTECTION

Synopsis submitted in fulfillment of the requirements for the Degree of

DOCTOR OF PHILOSOPHY

By

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DECLARATION BY THE SCHOLAR

I hereby declare that the work reported in the Ph.D. thesis entitled **“Novel Techniques for Improving the Performance of Digital Audio Watermarking for Copyright Protection”** submitted at **Jaypee Institute of Information Technology, Noida, India,** is an authentic record of my work carried out under the supervision of **Dr. Vikas Saxena and Prof. J.P. Gupta**. I have not submitted this work elsewhere for any other degree or diploma. I am fully responsible for the contents of my Ph.D Theses.

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Date …………………………………………..

SUPERVISOR’S CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled “**Novel Techniques for Improving the Performance of Digital Audio Watermarking for Copyright Protection**”, submitted by **Tribhuwan Kumar Tewari** at **Jaypee Institute of Information Technology, Noida**, **India,** is a bonafide record of his / her original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

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SYNOPSIS

The synopsis being put forward is based on the research work that develops novel audio watermarking schemes using Discrete Cosine Transform (DCT), Singular Value Decomposition (SVD) for improving the performance of audio watermarking.

1. Introduction:

The availability of multimedia in digital form has been a boon for multimedia industries, multimedia creators for decades. There are numerous advantages of having multimedia contents in digital form against an analog form. Few are ease of storage, ease of copying, ease of distribution, ease of encryption and decryption etc. **[1].** With these ease of operations which can be done on multimedia data, the illegal distribution and illegal sharing of multimedia data on the internet and also off the internet has increased many fold. Consequently, multimedia content providers i.e. authors, publishers are discouraged & damped to grant the distribution of their document on the networked environment. The intellectual property authentication has become an issue of concern **[2].**

There is a huge financial as well as loss of employment to many due to piracy and illegal distribution. A study by Institute of Policy information (IPI) approximates the loss of 12.5 billion USD for US economy annually due to multimedia piracy **[5]**. In addition to this huge monitory loss, there is a loss of as many as 70,000 jobs annually. A similar report on Australian Multimedia industries on behalf of Australian Federation Against Copyright Thefts (AFACT) in Feb 2011, estimates the annual revenue loss to be 1.37 billion $**[6].** As far as the loss due to piracy in India is concerned, study released by U.S. India Business Council (USIBC) showed as much as Rs. 16,000 crores loss each year due to piracy and 800,000 direct jobs lost as a result of theft and piracy. This is hugely afflicting India's entertainment industry **[7].** The piracy of music also shares appreciable part of the total revenue loss due to multimedia piracy. One of the India's largest e- commerce companies shut their online music store within one year of its infancy due to the online piracy and methods to combat the same **[12]**.

Unauthorized use of multimedia data creates a number of problems. There are some solutions to combat and reduce piracy. One of the solutions for dealing with the said problem trust on the cryptographic techniques. The encrypted form of the media is provided and it is controlled by encryption algorithm and the security key. Second solution is the copy control mechanism like DRM (Digital Right management) **[8 - 11].** The problem with both techniques is that once the media is decrypted it is open to all kind of modifications and replications. Also, there is no means through which after replication is done by an unauthorized person, the source of replication can be traced. Another category of methods aims at embedding the propriety information on the header of the media format. But these methods are not successful as changing just the format eliminates the propriety information. As against to embedding the copyright information onto the header, if the propriety information or the author/owner specific information is embedded on to the content of the media itself then the previous problem can be solved. Digital watermarking is a technology based upon the principle mentioned above. It aims at embedding the desired information onto the actual content of the multimedia in such a way that there are no perceptual artifacts in addition to robustness against removal by any means. In order to protect the interest of the content providers and counterfeiting piracy, watermarking proves to be a viable solution. According to a recent survey/report by Digital Watermarking Alliance the legal downloads will increase by 3% and illegal downloads will decreases by 42% for music files if the illegal downloader's will be told about the digital watermarking technology **[7]**. Digital watermarking proves to be a legal tool in Farrugia's case and many more cases of piracy. Although watermarking multimedia is governed by almost common fundamental concept, they mostly differ in the content of representation of the multimedia and system model i.e. Human Auditory System (HAS) or Human Visual System (HVS) used to perceive that media.

As compared with image and video watermarking, audio watermarking attracts the attention of the researchers lately as audio watermarking is more challenging. There are three main reasons which make the watermarking on audio as more challenging. Firstly, the audio signal carries very less redundant information that can be used for watermark embedding. Secondly, the human auditory system (HAS) is more complex and thirdly the HAS is more sensitive to small alteration on the cover audio signal. The HAS is more sensitive than the human visual system (HVS). The audio watermarking can be used with image watermarking for watermarking the videos also. Four main requirements imperceptibility, robustness security and payload should be met by the watermarking schemes. The weight given to each of the requirement depends upon the application for which the scheme is used. Imperceptibility requires the original and the watermarked audio to be indistinguishable. Robustness requires the retrieval of the watermark from the watermarked audio even after it is subjected to any attack. These attacks include re-quantization, re-sampling, amplification, noise addition, analog to digital or digital to analog conversion and compression attacks such as Advance Audio Codec (AAC), Moving Picture Expert Group (MPEG) 1 layer 3 (MP3). Security requires the watermark to be irretrievable and irremovable even if the extraction algorithm is known to the malicious user. Payload is the least talked about requirement which is the watermark carrying capacity and given as the number of bits of watermark that can be embedded per second on the cover audio. If the payload of the scheme is high, then hiding multiple copies of the watermark becomes easy which enhances the correct detection/extraction rate of the retrieved watermark.

So, **in this thesis**, the problem in digital watermarking of audio for protection of copyright and preventing online piracy is addressed. Audio watermarking schemes based on DCT and SVD are developed for improving the performance of watermarking schemes in terms of robustness, imperceptibility, payload and security. The need for unique watermark for digital watermarking is also addressed. Further, module for unique watermark generation using the auditory features extracted from the speech of any individual is developed.

2. Audio Watermarking :

Audio watermarking is defined as a technique in which the owner specific information or the cover audio tracking information etc. is embedded on to the cover audio signal in such a way that there is no perceptual difference between the original and the resultant audio. The embedded information is referred as the watermark and the resultant audio is referred as the watermarked audio signal. The embedded information should be extracted/ detected from the watermarked audio whenever required even if the watermarked audio is manipulated to give the feel like original. The different audio watermarking schemes exploits the deficiency of HAS. Audio watermarking mainly involves the use of two separate algorithms. First is the embedding algorithm and the second is the extraction/detection algorithm. The typical embedding and extraction modules of audio watermarking can be pictorially represented using the following figures.

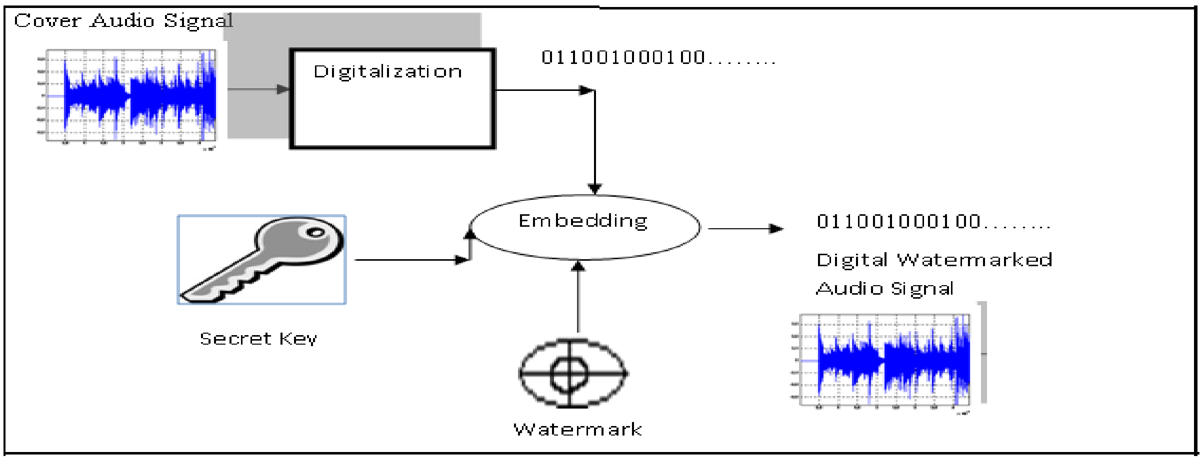

Figure 2.1 Watermark Embedding Block

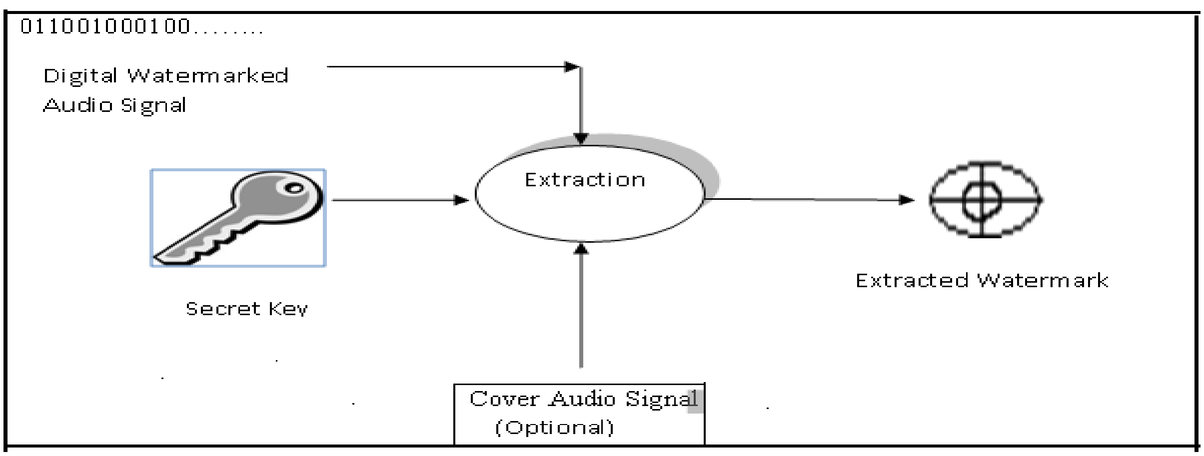

Figure 2.2 Watermark Extraction/Detection Block

Depending upon the requirement of original audio and tracing of the copyright information (like ownership protection applications) at the time of authentication /investigation /detection/ extraction, audio watermarking can be mainly categorized into the informed source or uninformed source watermarking. When the destination watermark information (like fingerprinting applications) is to be traced the watermarking schemes are categorized as informed destination or uninformed destination schemes. In principle, whether the original audio information is required or not at the time of extraction/detection of the watermark makes the watermarking schemes as informed or uninformed. In practical situations, mostly as the original audio is not available, the **thesis mainly focuses on the uninformed watermarking schemes.** Focus is on the development of improved schemes with security, robustness and high payload maintaining the imperceptibility.

The watermarking schemes in the literature use arbitrary images or pseudo random numbers as watermark. Patenting copyright on an arbitrary images or key(s) to generate pseudo random number is difficult which are mainly used as watermark. Thus, the schemes become unacceptable when the watermark itself becomes the public property i.e. can be used by anyone. The watermark used by one can be used by many more individuals also and claiming the copyright on such watermark and ultimately on the cover media becomes very difficult. If the watermark used by one cannot be generated by others then this situation can be omitted. **This issue is addressed in the thesis and development of a watermark generation module is done**. The developed module generates a watermark using the auditory features extracted from an individual which is unique.

On the basis of the domain in which watermark is embedded, the audio watermarking schemes are categorized as time domain, transform domain and compressed domain watermarking. Further the schemes can be categorized into Bit Modification or Substitution **[14 -16],** Spread Spectrum **[17 -19]**, Phase Coding and Phase modulation **[20-22]**, Echo Hiding [**23 -26**], Patchwork **[27 -29]**, Histogram **[30]** etc., based techniques as far as embedding strategies are concerned. The transform domain watermarking techniques are based on the transform used and it is required that the transform be reversible. The typical transform used are DCT **[31-35]**, Discrete Wavelet Transform (DWT) **[36- 39]**, Discrete Sine Transform (DST) **[40]**, Discrete Fourier Transform (DFT), Fractional Fourier Transform (FRFT), Fast Fourier Transform **[41-43]**, SVD **[44-50]** etc. There are schemes which use dual transforms also. DCT, DST, DWT, FRFT are all used to compact the energy in few transform coefficients but all the transform doesn’t work equally good as far as watermarking of audio is concerned.

The **LSB (Least Significant Bit) based schemes [14 -16]** modify a bit of individual sample or bits of group of samples to embed one watermark bit such that the difference in the watermarked and the original should be least. These schemes have a high payload and low computational complexity but bear a low robustness even to common signal processing like analog to digital conversion and vice versa, filtering etc. The current research on LSB based schemes is in shifting the bit layer of embedding towards the most significant bits (MSB) **[14].**

The **Spread Spectrum schemes [17-19]** exploit the deficiency of HAS insensitivity to small change in amplitude. The embedding of watermark can be done directly in time domain and in the transform domain as well. They bear a modest payload too. These schemes show appreciable robustness to attacks and secured behavior but the disadvantage is the original signal interference because of which the imperceptibility is at stake most of the times. In addition, even for closed loop attack i.e. without any attack the complete retrieval of the watermark data is not guaranteed. These schemes are vulnerable to watermark estimation attacks and not suitable for multiple watermark embedding applications. As these schemes use detection based strategy and thus is not suitable for real time applications.

The **Phase Coding schemes [20 -22]** are simple schemes in which the phase of the audio signal is modified according to the watermarking bit. The schemes take advantage of the deficiency of HAS to detect absolute phase and small phase difference. These schemes exhibits a large signal to noise ratio (SNR) which is the metric used for imperceptibility of the watermarked media but they are having very low payload. Another category that is popular among phase coding schemes is Phase Modulation. These schemes carry a relatively higher payload.

Echo Hiding based watermarking schemes [23 -26] exploits HAS insensitivity to temporal as well as frequency masking. The watermark bit is added through two different echo kernels and the strength of the echo is controlled by a scalar. These schemes show good imperceptibility for smaller value of the scalar as the echo is tuned according to the psychoacoustic model of HAS but robustness is reduced. Higher value of the scalar reduces the imperceptibility. In the early stage, there is no security involved in these schemes but later on schemes are developed that uses frequency hopping , scrambling etc. to introduce security. The echo hiding methods differ in the echo kernel used and the number of echoes used. Larger number of echoes with same strength increases the robustness for the same level of imperceptibility. The payload of the echo based watermarking methods depends upon the psychoacoustics shaping.

Patchwork based watermarking schemes [27- 29] use two segments or patches with same statistical properties like mean and then modify each sample of the patches in opposite direction to embed the watermark bits. The expected value of difference in the mean detects the watermarking bit. Bender gives the core idea of Patchwork schemes and he applied it for image watermarking. Arnold extended the scheme for audio watermarking and modifies the original by applying it in transform domain instead of spatial domain as was done by Bender. Further, he used multiplicative approach as against the additive approach used by Bender for modifying the samples. The successful detection demands for a large variance among the patches which implicitly requires the length of the patches to be large. Successive research is done to embed the watermark bits without increasing the variance and called as Modified Patchwork Algorithm (MPA).Since the Patchwork methods are based on the assumption that the statistical property of the two selected patches for watermark embedding is the same which is not true practically, these schemes suffers from false detection. The payload varies as in these schemes it is dependent upon the number of patch pairs with comparable mean etc.

Transform domain watermarking schemes process the audio in transform domain for embedding. DCT exhibits the property of energy compaction of the signal into fewer transformed coefficients and proved to be a good transform as far as compaction of energy and audio watermarking is concerned. The low frequency DCT coefficients carry appreciable amount of energy and change in the lower frequency DCT coefficients lead to greater distortion. Modification of the high frequency components won't produce much of the distortion but the robustness is questionable. Simple filtering operation may lead to the complete removal of watermark data. So, there is a tradeoff of robustness and imperceptibility in selection of the coefficients. The mid band frequency coefficients shows robustness to common signal processing operations like analog to digital conversion, digital to analog conversion, re-sampling, re-quantization etc. Also, distorting these coefficients up to a smaller extent for watermark embedding doesn't make perceptible change in the resultant audio. The different schemes which embed the data in DCT transform domain in principle differs in the no. of coefficients taken for embedding, the type of coefficients i.e. low, high or middle, ac or dc coefficients, the methodology used for embedding and finding the coefficients for watermark embedding which should produce minimum distortion and maximum robustness.

Singular values(SV) obtained from the SVD also show the same type of behavior as far as perceptibility of the resultant audio and the robustness is concerned. The use of the SV for watermark embedding is based on the fact that if there is a slight change in the SV, it will not disturb the transparency of the image or audio and also there is no prominent change in SV if the image or audio is subjected to common signal processing operations. So, SVD-based audio watermarking algorithms **[45-48 ,50]** exploits this property to add the watermark information to the SV of the diagonal matrix or the columns of the unitary matrices in such a way that imperceptibility /inaudibility is not disturbed and robustness requirements of effective digital audio watermarking algorithms is achieved. The SVD based method differs in the different SV use and the methodology through which the embedding is done using SV. Apart from using the SV, Wang **[49]** used the unitary matrix for embedding of watermark bits. As far as the use of SVD in audio watermarking is concerned, it is only recently done and still in the exploration state.

So, the thesis discusses improving and developing the audio watermarking schemes using DCT and SVD.

On the basis of robustness requirement, the watermarking schemes are further categorized into robust **[31, 35, 37]**, fragile and semi fragile watermarking schemes. Since the intellectual property right infringement requires the extraction of the owner information from the disputed copy, the **thesis focuses on robust watermarking**. The fragile watermarking schemes are used for multimedia authentication. The following section laid down the foundation of our research work with identified gaps and our corrective measures to overcome it.

3. Identified Issues:

On the basis of the literature review, it can stated that the main issue with the audio watermarking and with all the watermarking schemes which uses other type of cover object is to make the watermarked object (which is embedded with extra information) robust to attacks while maintaining the imperceptibility. This issue become more serious in case of audio watermarking because of the sensitivity of HAS. The requirements of the audio watermarking contradict with each other as robustness requires the watermark to be embedded in the prominent portion of the audio so that it can't be removed through attacks. But this will definitely reduce the imperceptibility. Also, with increase in watermark embedding density (i.e. payload expressed in bits per second (bps)) the imperceptibility decreases. Therefore, an optimal tradeoff is required to be maintained for imperceptibility, robustness and payload for the watermarking schemes using better embedding strategies and thus it is still an open problem. Some additional issues are identified which are as follows.

Issue 1: Although, the DCT based watermarking schemes have low embedding complexity but the use of low frequency coefficients or the DC coefficients as the watermarking locations leads to less imperceptibility. There is a need to give attention to the use of selected frequency coefficients and better embedding strategy to provide a good balance between imperceptibility, payload and robustness. Embedding watermark on a single coefficient may not sustain robustness against attacks but group of coefficients when used for data embedding has higher probability to show robustness. Also, improvement on these watermarking schemes is required to carry variable payloads for adjustability requirement with imposed security.

Issue 2: Uninformed destination based watermarking schemes which are mostly used for audio fingerprinting requires multiple copies of the audios to be watermarked using different watermarks. But, estimation attacks tries to remove the watermark by analyzing multiple watermarked copies. There is a need to develop improved uninformed destination based watermarking schemes which can combat against estimation of the watermark, unintentional mp3 compression and direct manipulation of watermarked samples or coefficients used for embedding copyright information simultaneously, with in an audio.

Issue 3: Very less work is reported on analyzing the affect of mp3 compression on the watermarked audios. The watermarking schemes in which watermarking is done on already compressed audios are prone to format change attacks. The watermarking scheme that can be applied to uncompressed audios and robust to mp3 compression need to be developed based on the study of the effect of mp3 compression on the individual blocks of audios used to embed watermarking bits.

Issue 4: The watermarking schemes in the literature use arbitrary images or pseudo random numbers as watermark. Patenting copyright on arbitrary images or key(s) to generate pseudo random number is difficult which are mainly used as watermark. Thus, the schemes become unacceptable when the watermark itself becomes the public property i.e. can be used by anyone. Also, there can be situation when the watermark itself can be used to mislead the ownership. To defame a person, arbitrary watermark used by an owner can be used by a malicious person to watermark other's creations. The watermark used by one can be used by many more individuals also and claiming the copyright on such watermark and ultimately on the cover media becomes very difficult. Less attention is paid on the need to use unique watermark preferably those generated from biometric features to combat against ambiguous situation and defamation of an individual.

4. Thesis Objectives:

Based on the literature review done and the issues identified along with the main issue of watermarking, the thesis objective is oriented towards improvement of the uninformed source and destination based watermarking schemes with respect to imperceptibility, robustness, security and payload. The watermarking schemes proposed are source based i.e. ownership detection as well as destination based i.e. pirate detection. The DCT and SVD transform is used for embedding as they are well accepted in watermarking domain. The robustness against the common signal processing attacks along with compression attack is must as the audios are provided on the networked environment with minimum bandwidth using compressed forms. The module to generate a unique watermark for owner authentication and tracing of the pirate also seems to be an utmost requirement.

The objectives of the thesis are summarized below as.

Objective 1: The First objective is to develop improved uninformed audio watermarking schemes using selected frequency DCT coefficients which is capable of carrying variable payload with good imperceptibility and is robust to compression attacks in addition to the common signal processing attacks. This objective covers i**ssue 1.**

Objective 2: The SV's obtained from the SVD transformation inherently shows some sort of robustness to attacks and small change in the SV's doesn't make perceptible change on the cover audio object. **The second objective is to** develop an improved uninformed secured audio watermarking schemes using SVD which is capable of carrying high payload and is robust to compression attacks and direct manipulation of the SVs. This addresses **issue 2**.

Objective 3: For robustness against compression attack specially the mp3 attack, the blocks with in an audio are required on which there is least effect of compression along with robustness to other common signal processing attacks. So, the third objective is to identify such blocks after analyzing the effect of mp3 compression at different compression rate and developing embedding strategy on the individual blocks to improve the robustness. This resolves **issue 3**.

Objective 4: For dealing with **issue 4** a unique watermark generation module is required which is capable of producing a unique watermark. The unique watermark should be able to combat against the problem which arises due to common ambiguous watermark.

5. Thesis Organization:

The thesis is organized in 7 chapters. Apart from introduction given in Chapter 1 and literature survey work given in chapter 2 **[51],** the summarized content of the other chapters are given below:

In **Chapter 3,** we proposed and developed two uninformed DCT based audio watermarking schemes which use the mid band DCT coefficients for watermark embedding. Experiments are conducted for finding the mid band frequency coefficients on which the effect of mp3 compression and common signal processing operations is minimum. The schemes use the quantization of mean or the Euclidian norm of the mid band DCT coefficients for watermark embedding. The audio is segmented and only those segments which have a minimum energy greater than a threshold are selected for watermark embedding. Selection of the threshold controls the payload, imperceptibility and robustness. The second proposed scheme uses a security key additionally and chaotically permutes the watermark before embedding. On the basis of the security key the embedding blocks along with embedding strategy is decided. The superior performance of the proposed schemes with suitable DCT based schemes is due to segment selection and the selected mid band DCT coefficients for watermark embedding. Both the schemes showed a good robustness to attacks with high imperceptibility and moderate payload **[54].** As a preliminary, improved mid band DCT coefficients manipulation scheme is applied on the image and tested for imperceptibility and robustness. As against the traditional image watermarking schemes using the DCT coefficients where the DCT coefficients are used for watermark embedding, our approach used the sub band DCT coefficients obtained after averaging and differencing of the adjacent samples of the image. The scheme shows high robustness to compression in addition to common image processing operations **[53].**

In **Chapter 4**, uninformed segmental SVD based audio watermarking schemes with high payload are proposed and developed. The first proposed scheme uses the appropriate SV of the individual block of the audio segment for embedding the watermark bit. The method is superior to the methods which require the original matrices for extraction of the watermark. The second scheme uses a segmental approach in which a watermarking bit is embedded on to the SVD matrix obtained from small segments of the cover audio. For embedding, second and the third norm are used depending upon the selection criteria. Embedding using the second norm and the third norm increases the robustness when compared with the mean but as the order of the norm is increased the imperceptibility decreases for similar level of robustness. In both the schemes, prior to singular value decomposition and embedding, the matrix is permuted using Baker’s map for providing security to the SV’s used for embedding. Baker’s map produces the permuted chaotic version of the matrix through a key. The correctness and the efficiency of Baker’s map have already being proved when used with image as a two dimensional matrix. The chaotic mapping is used on the watermark and also the matrix obtained from the segmented audio prior to decomposition into singular values. The security is imposed through the key used for chaotic mapping. The method is superior to the SVD based schemes in which there is a direct manipulation of the singular values for watermark embedding. Also, chaotic mapping is done without compromising the quality of the watermarked audios. The security is also imposed on the watermarking schemes based on SVD which was lacking in traditional schemes.

In **Chapter 5,** a semi informed scheme is proposed which uses the schemes proposed in chapter 3 and 4 to attain good robustness against mp3 compression. Although, the previous schemes developed show good robustness against mp3 compression attacks at lower compression rate, the watermark retrieval at higher compression rate becomes difficult. Preliminary study on the effect of compression on the pre processed watermarked audio undergone mp3 compression at different rate is done. The correctly retrieved watermark bits identify the appropriate embedding blocks iteratively, rejecting the blocks which were not able to sustain compression. These blocks are finally used for watermark bit embedding. The scheme uses the index of such identified blocks to convey the information to the extraction module. Using the approach, the watermarking scheme produces watermarked audios that are inherently robust to compression attacks at different compression rates in addition to being robust against other attacks.

In **Chapter 6,** need for unique watermark is discussed and a module for generation of unique watermark is developed. This module generates a watermark using the auditory features extracted from an individual which is unique. Experiments show that thresholding the selected group of Mel frequency cepstral coefficients (mfcc) for every block of speech sequence generates a unique binary sequence. The binary sequence thus produced can be used as a watermark. The threshold can act as the security key of the watermark. Later on the binary sequence can be generated using the threshold key and the vector sequence obtained from individual segments. The uniqueness of the binary sequences are checked through the cross correlation coefficients obtained by taking all the vectors produced through the process corresponding to individual speech data taken from every individual **[52]**.

In **Chapter 7,** the conclusion on the result obtained and the future scope is given.

6. Conclusion:

The proposed mid band DCT based schemes presented in chapter 3 shows that the use of the group of mid band DCT coefficients with better embedding strategy improves the robustness towards filtering and compression attacks. Also, the obtained payload of the schemes is as high as 86bps. The proposed schemes have an average SNR of more than 35 dB and are robust to most common signal processing with moderate robustness towards mp3 attack also. The SNR of watermarked audio and robustness to attacks is comparable if all the DCT coefficients or mid band DCT coefficients are used for embedding when mean is modified. But, the SNR of the watermarked audio and robustness to attacks using the Euclidian distance of the DCT coefficients for watermark embedding is better than all DCT coefficients scheme.

The proposed SVD based schemes in chapter 4 carry a high payload of as high as 441bps with a SNR of more than 30 dB. These schemes can be more suitable in the applications where a large amount of information is required to be stored with in an audio. The schemes show robustness towards most of the signal processing attacks along with moderate robustness towards mp3 compression at high compression rate. Security is imposed in the SVD based schemes without compromising the imperceptibility of the watermarked audios through Baker's map. The order of the norm used for embedding watermark is inversely proportion to the SNR of the watermarked audios.

The proposed SVD based scheme presented in chapter 5 is inherently robust to mp3 compression attacks and also survives most of the signal processing attacks with an average SNR of more than 30 dB and an average payload of 220 bps.

The watermark generation module presented in chapter 6, generates watermark that are unique. The generated watermarks can be used as authentic copyright information of an individual and don't require patenting the copyright information to be embedded on the original cover audios.

KEYWORDS: *Intellectual Property Right, Digital Audio Watermarking, Digital Image Watermarking, Digital Right Management (DRM), Audio Fingerprinting, Discrete Cosine Transform (DCT), Singular value Decomposition (SVD), Mp3 Compression, Signal to Noise Ratio (SNR), Normalized Correlation Coefficient (NCC).*

REFERENCES:

[1]. I. Cox, M. Miller, "Electronic watermarking: the first 50 years", *in Proc. of the IEEE workshop on multimedia signal processing*, Cannes, USA, pp. 225–230, 2001.

[2]. F. Petitcolas, R. Anderson, MG Kuhn, “Information hiding: a survey”, *in Proc. of the IEEE special issue on protection of multimedia content*, vol. 87, no. 7, pp 1062–1078,1999.

[3]. “The Deterrent Effect of Digital Serial Numbers on Illegal File-Sharing and Downloading”. [Online]. Available: http://www.digitalwatermarkingalliance.org/docs/papers/DWA_WhitePaper_PiracyDeterrence.pdf

[4]. “IFPI digital music report 2011”. [Online]. Available: www.ifpi.org/content/library/dmr2011.pdf

[5]. “The True Cost of Sound Recording Piracy to the U.S. Economy”. [Online]. Available: http://www.ipi.org/ipi_issues/detail/the-true-cost-of-sound-recording-piracy-to-the-us-economy.

[6]. “About AFACT”, 2011. [Online]. Available: www.afact.org/index.php/news/sydney_woman_fined_7000_for_movie_theft

[7]. “The Effects of Counterfeiting and Piracy on India's Entertainment Industry”. [Online]. Available: http://www.prnewswire.com/news-releases/piracy-in-indias-entertainment-industry-causes-huge-losses-to-indian-economy-57149602.html

[8]. L. Qiong, S. Reihaneh , S. Nicholas, “Digital Rights Management for Content Distribution”, *in Proc. of the Australian information security workshop*, vol. 21, pp.49-58, 2003.

[9]. Z. Zhang, “Digital Rights Management Ecosystem and its Usage Controls: A Survey”, *Journal of Digital Content Technology and its application*, vol. 5, no. 3, pp. 255- 272, 2011.

[10]. S.Kwok, “Digital Rights Management for the Online Music Business”, *ACM SIGecom Exchanges*, ACM, New York, USA, vol.03, no.03, pp.17-24, 2002.

[11]. S. Muller, S. Katzenbeisser, “A New DRM Architecture with Strong Enforcement”, *in Proc. of Availability, Reliability, and Security conference*, Krakow,pp. 397-403, 2010.

[12]. “Flipkart to shut down Flyte MP3 Music store on June 17”, [Online]. Available: http://gadgets.ndtv.com/internet/news/flipkart-to-shut-down-flyte-mp3-music-store-on-june-17-372868

[13]. E. Ambikairajah, “Auditory masking and MPEG-1 audio compression”, *Electronics & communication engineering journal*, vol. 9, no. 4, pp.165-175, Aug 1997.

[14]. W. Cao, "Bit Replacement Audio Watermarking using Stereo Signals", *in Proc. of Intl. Conf. on New Trends in Information and Service Science, (NISS '09)*, pp. 603-606, 2009.

[15]. N. Cvejic and T. Seppanen, "Increasing robustness of LSB audio steganography by reduced distortion LSB coding", *Journal of University Computer Science*, vol. 11, no. 1 pp. 56 -65, 2004.

[16]. N. Cvejic, and T. Seppanen, "Digital Audio Watermarking Techniques and Technologies", *Information Science reference*, New York, pp.1-11, 2007.

[17]. R. Martinez-Noriega, M. Nakano, K. Yamaguchi, "Self-synchronous time-domain audio watermarking based on coded-watermarks", *in Proc. of Intl. Conf. on Intelligent Information Hiding and Multimedia Signal Processing (IIH-MSP)*, Darmstadt, pp 135–138, 2007.

[18]. C. Laftsidis, A.Tefas, N. Nikolaidis I. Pitas, "Robust multibit audio watermarking in the temporal domain", *in Proc. of the IEEE international symposium on circuits and systems*, pp. 933–937, 2003.

[19]. Z. Liu, A. Inoue,, "Audio watermarking techniques using sinusoidal patterns based on pseudorandom sequences", *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 13, no. 8 ,pp. 801 – 812, Aug. 2003.

[20]. Y. Yardimci, A. E. Cetin, and R. Ansari, "Data hiding in speech using phase coding," *in Proc. of Euro speech Conf.*, Rhodes, Greece , pp 1-4, Sep 1997.

[21]. A. Sek, Y. Suzuki, R. Nishimura, and K. Sonoda, "Phase rotation thresholds and its use in watermarking technique," *Acoustical Society of America Journal*, vol. 113, no. 4, pp. 2288-2288, 2003.

[22]. T. Ciloglu, "An improved all-pass watermarking scheme for speech and audio", *in proc. of IEEE Intl. Conf. on Multimedia and Expo, ICME 2000*. New York, USA, pp. 1017-1020, 2000.

[23]. H.J. Kim, Y.H. Choi, "A novel echo-hiding scheme with backward and forward kernels", *IEEE Trans. On Circuits Systems for Video Technology*, vol. 13, no. 8, pp. 885-889, 2003.

[24]. B.S. Ko , R. Nishimura, Y. Suzuki, "Time-spread echo method for digital audio watermarking", *IEEE Trans.on Multimedia*, vol. 7,no. 2,pp. 212-221, 2005.

[25]. Y. Erfani, S. Siahpoush, "Robust Audio Watermarking Using Improved TS Echo Hiding", *Digital Signal Processing*, vol. 19, no. 5, pp. 809-814, 2009.

[26]. T.C. Oscal, W. Wen-Chih, “Highly Robust, Secure, and Perceptual-Quality Echo Hiding”, *IEEE Transactions on Audio, Speech and Language Processing*, vol. 16, No. 3, pp 629-638, Mar. 2008.

[27]. K. Yeo, H. J. Kim, “Modified patchwork algorithm: The novel audio watermarking Scheme”, in Proc. *IEEE Int. Conf. Information Technology: Coding and Computing*, Las Vegas, NV, pp. 237- 242,April 2–4, 2001.

[28]. K. Yeo, H. J. Kim, “Modified Patchwork Algorithm: A Novel Audio Watermarking Scheme”, *IEEE Transactions On Speech And Audio Processing*, vol. 11, no. 4, pp 381-386, July 2003.

[29]. N.K. Kalantari, “ Robust Multiplicative Patchwork Method for Audio watermarking”, *IEEE Transactions On Audio, Speech, And Language Processing*, vol. 17, no. 6,pp. 1133-1141,2009.

[30]. Z. Xiaoming, X.Zhang, Y. Xiong , Y. Zhaoyang , “Histogram Specification-based Audio Watermarking Technology against Filtering Attacks in Time Domain” *Intl. Symp. on Electronic Commerce and Security,* Guangzhou City, pp. 951 – 956, 3-5 Aug. 2008.

[31]. Z. Zhou et. Al, “A Novel Algorithm for Robust Audio Watermarking Based on Quantification DCT Domain”, *in Proc. of Intl. conf. on Intelligent Information Hiding and Multimedia Signal Processing IIHMSP 2007*, Kaohsiung, vol. 1, pp. 441-444,2007.

[32]. W. Youngqi et al., “Asynchronous Audio Watermarking Algorithm Based on Chaotic Encryption in DCT Domain”, *in Proc. of Intl. Conf. on Information Science and Engineering*, ISISE 08, vol. 2, pp. 371-374, 2008.

[33]. H. Xiong et. al., “Robust audio watermarking based non-uniform DCT”, *in Proc. of Intl. conf. on Intelligent Computing and Intelligent Systems (ICIS 2010)*, Xiamen, pp. 585-588, 2008.

[34]. X. Zhang et.al., “An Audio watermarking algorithm transmitted via air channel in double DCT domain”, *in Proc. of Intl. Conf. on Multimedia Technology (ICMT 2011)*, Hangzhou, pp. 2926- 2936, 2011.

[35]. X. Zhang et. al., “A robust digital watermarking algorithm in DCT domain for air channel transmission”, *in Proc. of Intl. Conf. on Multimedia Technology (ICMT 2011)*, Hangzhou, pp. 2896-2899, 2011.

[36]. W. Lanxun, Y. Chao, P. Jiao, “An audio watermark embedding algorithm based on mean quantization in wavelet domain”, *in Proc. of the 8th international conference on electronic measurement and instruments*, Xian, vol. 2, pp 423–425, 2007.

[37]. S. Wu, J. Huang, D. Huang, Q. Yun, "Self-synchronized audio watermark in dwt domain", *in Proc. of the intl. Symp. on circuits and systems*, 2004, pp. 712–715

[38]. X. Xiaojuan, H. Peng , C.He, "DWT-based audio watermarking using support vector regression and subsampling", *in Proc. of the 7th international workshop on fuzzy logic and applications*, pp. 136–144, 2007.

[39]. A. Al-Haj, L. Bata, A. Mohammad , "Audio Watermarking using Wavelets", *First Intl. Conf. on Networked Digital Technologies (NDT '09)*, Ostrava, pp. 398 – 403,2009.

[40]. M. Fan, H. Wang, "Chaos-Based Discrete Fractional Sine Transform Domain Audio Watermarking Scheme",*Computers and Electrical Engineering*, vol. 35, no. 3, pp. 506-516, 2009.

[41]. X. Ling , J. Zhang; H. He, "Robust Audio Watermarking Scheme Based on Non uniform Discrete Fourier Transform", *IEEE Intl. Conf. on Engineering of Intelligent Systems,* pp. 1 – 5, 2006.

[42]. P.K. Dhar, J.M. Kim, "Digital Watermarking Scheme Based on Fast Fourier Transformation for Audio Copyright Protection", *Intl. Journal of Security and its Applications*, vol. 5, no. 2, pp. 33-48, 2011.

[43]. M. Fallahpour, D. Megias, "High Capacity Audio Watermarking Using FFT Amplitude Interpolation", *IEICE Electronics Express*, vol. 6, no. 14, pp.1057-1063, 2006.

[44]. A. Mohammad, S. Shaltaf, "An improved SVD-based watermarking scheme for protecting rightful ownership", *Signal Process,* vol. 88, pp. 2158–2180, 2008.

[45]. R. Liu, T. Tan., "An SVD-based watermarking scheme for protecting rightful ownership", *IEEE Trans. On Multimedia*, vol. 4 no. 1, pp. 121–128, 2002.

[46]. V. Bhat, K.I. Sengupta, A. Das, "An audio watermarking scheme using singular value decomposition and dither-modulation quantization", *Multimedia Tools and Applications* ,vol. 52, no. 2-3, pp. 369-383, April 2011.

[47]. V. Bhat, et al., "A New Audio Watermarking Scheme Based on Singular Value Decomposition and Quantization", *Circuits Syst. Signal Process*, vol. 30, pp. 915–927, 2011.

[48]. X. Zhang , K. Li, Comments on "An SVD-based watermarking scheme for protecting rightful ownership", *IEEE Trans. Multimedia* ,vol.7, no. 2, pp. 593–594, 2005.

[49]. J. Wang, R. Healy, J. Timoney, "A robust audio watermarking scheme based on reduced singular value decomposition and distortion removal", *Journal of Signal Processing,* vol. 91, no. 8, pp. 1693-1708, Aug.2011.

[50]. Y. Wu, “On the Security of an SVD-Based Ownership Watermarking”, *IEEE Transactions on Multimedia*, vol. 7, no. 4, pp. 150 – 154, Aug. 2005.

SCHOLAR’S PUBLICATIONS

[51]. T. K. Tewari, V. Saxena, J. P. Gupta, “Audio Watermarking: Current State of Art and Future Objectives”, *International Journal of Digital Content Technology and its Applications*, vol. 5, no.7, pp. 306- 314, July 2011.

[52]. T. K. Tewari, V. Saxena, J. P. Gupta, “A Novel Approach to Generate Watermarks Using Auditory Features for Audio Watermarking”, *Journal of Theoretical and Applied Information Technology*, vol. 32, no. 2, pp. 155- 162, Jan 2012.

[53]. T. K. Tewari, V. Saxena, “An Improved and Robust DCT Based Digital Watermarking Scheme”. *International Journal of Computer Applications*, vol-3, no. 1, pp. 28–32, June 2010.

[54]. T. K. Tewari, V. Saxena, J. P. Gupta, “A Digital Audio Watermarking Scheme using Selective Mid band DCT coefficients and Energy Threshold” ,International journal of Speech Technology, **Springer**, vol. 17, no. 4 pp. 365-371, Dec. 2014.

[55]. T. K. Tewari, V. Saxena, J. P. Gupta, “A High Payload Audio Watermarking Scheme using SVD and Baker’s map encryption”. [Communicated to International Journal of Computer Applications in Technology]

[56]. T. K. Tewari, V. Saxena, J. P. Gupta, “A Novel Audio Watermarking Scheme inherently robust to mp3 compression attacks”. **[**Under Writing]