Digital Watermarking Scheme Based on Fast Fourier Transformation for Audio Copyright Protection

Pranab Kumar Dhar[*], Jong-Myon Kim[1**]
[*]*Department of Computer Science and Engineering, Chittagong University of Engineering and Technology, Chittagong-4349, Bangladesh*
[**]*School of Computer Engineering and Information Technology, University of Ulsan, San 29, Mugeo 2-Dong, Nam-Ku, Ulsan, 680-749, Korea*
pranab_cse@yahoo.com, jmkim07@ulsan.ac.kr

Abstract

Digital watermarking is now drawing attention as a new method of protecting digital content from unauthorized copying. This paper proposes a new watermarking scheme in based on Fast Fourier Transformation (FFT) for copyright protection of digital audio. In the proposed watermarking scheme, the original audio is segmented into non-overlapping frames. Watermarks are embedded into the selected prominent peaks of the magnitude spectrum of each frame. Informal listening reveals excellent imperceptibility of the embedded watermark. The proposed watermarking scheme is tested by various kinds of attack to demonstrate the robustness of watermarking. Simulation results suggest that the imperceptible watermarks embedded with the proposed method are highly robust against various kinds of attacks such as noise addition, cropping, re-sampling, re-quantization, MP3 compression, and low pass filtering. We observe that the proposed scheme shows similar robustness compare to Cox's method. In addition, the proposed method provides better performance than Cox's method in terms of SNR result because of embedding watermarks into the selected prominent peaks of magnitude spectrum of each frame of the original audio signal. Our proposed scheme achieves SNR (signal-to-noise ratio) values ranging from 20 dB to 28 dB, in contrast to Cox's method which achieves SNR values ranging from only 14 dB to 23 dB.

Keywords: *Copyright Protection, Digital Watermarking, Digital Audio, and Fast Fourier Transform.*

1. Introduction

The recent growth in computer networks, and more specifically, the World Wide Web, has allowed multimedia data to be easily distributed over the Internet. Digital watermarking has drawn extensive attention for copyright protection of multimedia data. A digital audio watermarking is a process of embedding watermarks into audio signal to show authenticity and ownership. Audio watermarking should meet the following requirements :(a) Imperceptibility: the digital watermark should not affect the quality of original audio signal after it is watermarked; (b) Robustness: the embedded watermark data should not be removed or eliminated by unauthorized distributors using common signal processing operations and attacks; (c) Capacity: capacity refers to the numbers of bits that can be embedded into the audio signal within a unit of time; (d)

[1] Corresponding author

Security: security implies that the watermark should only be detectable by the authorized person. These requirements are often contradictory. Since robustness and imperceptibility are the most important requirements for digital audio watermarking, these should be satisfied first. Watermarking is used for owner identification, royalty payments, and authentication by determining whether the data has been altered in any manner from its original form.

A watermark must be embedded in the data in such a way that it is imperceptible by the user. Moreover, the watermark should be inaudible or invisible to prevent unauthorized detection and removal. The watermark should also have similar compression characteristics as the original signal and be robust to any manipulations or signal processing operations on the host data, such as filtering, compression, re-sampling, re-quantization, cropping, noise attack, etc. The watermark should also be embedded directly in the data. The signal should be degraded when the watermark is removed through any unauthorized means.

Compared to image and video signals, audio signals are represented by much less samples per time interval. This indicates that the amount of information that can be embedded robustly and inaudibly is much lower than for visual signal. An additional problem in audio watermarking is that the human audible system (HAS) is much more sensitive than the human visual system (HVS), and that inaudibility is much more difficult to achieve than invisibility for images.

In this paper, we propose a new watermarking scheme based on fast Fourier transformation for audio copyright protection. The watermarks are embedded into the selected prominent peaks of the magnitude spectrum of each non-overlapping frame. Experimental results indicate that the proposed watermarking scheme provides similar robustness as Cox’s method [10] against several kinds of attacks such as noise addition, cropping, re-sampling, re-quantization, MP3 compression, and low-pass filtering. However, our proposed watermarking scheme outperforms Cox's method in terms of imperceptibility. Our proposed scheme achieves SNR values ranging from 20 dB to 28 dB, in contrast to Cox's method which achieves SNR values ranging from only 14 dB to 23 dB.

The rest of this paper is organized as follows. Section 2 provides a brief description of related research including Cox's method. Section 3 presents a generic watermarking scheme. Section 4 introduces our proposed watermarking scheme including watermark embedding process and watermark detection process. Section 5 compares the performance of our proposed scheme with Cox's method in terms of imperceptibility as well as robustness. Finally, section 5 concludes this paper.

2. Related Research

A significant number of watermarking techniques have been reported in recent years in order to create robust and imperceptible audio watermarks. Lie et al. [1] propose a method of embedding watermarks into audio signals in the time domain. Their algorithm exploits differential average-of-absolute-amplitude relations within each group of audio samples to represent one-bit information. It also utilizes a low-frequency amplitude modification technique to scale the amplitudes in selected sections of samples so that the time domain waveform envelope can be almost completely preserved. The authors of [2] propose a blind audio watermarking scheme which embeds watermarks into audio signal in the time domain. The strength of the audio signal modifications is limited by the necessity to produce an output signal for watermark detection. The watermark signal is generated using a key, and watermark insertion depends on the amplitude and the frequency of audio signal that minimizes the audibility of the watermarked signal. Ling et al. [3] devised a watermarking scheme based on non-uniform discrete Fourier transform (NDFT), in which the frequency points of embedding watermark are determined by using the secret key. Zeng et al. [4] describe a blind watermarking scheme that embeds watermarks into DCT coefficients by utilizing a quantization index modulation technique. The authors of [5] propose a watermarking system that embeds synchronization signals in the time domain in order to resist several attacks. Pooyan et al. [6] introduce an audio watermarking method which embeds watermarks in the wavelet domain. The watermarked data is then encrypted and combined with a synchronization code and embedded into the low frequency coefficients of the sound in wavelet domain. The magnitude of the quantization step and the embedding strength is adaptively determined according to the characteristics of the human auditory system. Wang et al. [7] propose a blind audio watermarking scheme using adaptive quantization against a synchronization attack. The multi-resolution characteristics of discrete wavelet transform (DWT) and the energy compression characteristics of the discrete cosine transform (DCT) are combined in this scheme to improve the transparency of the watermark. The watermark is then embedded into low frequency components by using adaptive quantization according to human auditory system. In [8], the authors propose a watermarking system in the 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 the human auditory system. Liu et al. [9] propose a blind watermarking scheme that takes the advantages of the attack-invariant feature of the cepstrum domain and the error-correction capability of BCH code to increase the robustness as well as the imperceptibility of audio watermarking.

In Cox's method [10] watermarks are embedded into the highest n DCT coefficients of a whole sound excluding the DC component according to the following equation:

$$v_i' = v_i(1+\alpha x_i) \tag{1}$$

where vi is a magnitude coefficient into which a watermark is embedded, xi is a watermark to be inserted into vi, α is a scaling factor, and vi' is an adjusted magnitude coefficient. The watermark sequence is extracted by performing the inverse operation of (1) represented by the following equation:

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

Cox's method provides good results in terms of robustness. However, this method cannot achieve good imperceptibility in terms of signal-to-noise ratio (SNR) because it embeds watermark into highest DCT components of the sound which sometimes affects the quality of the sound. To overcome this problem, we propose a new watermarking scheme which embeds watermarks into the selected prominent peaks of the magnitude spectrum of each non-overlapping frame. This provides better results than Cox's method in SNR aspect for watermarked audio signals, while keeping comparable robustness with Cox's method against several kinds of attacks.

3. Basics of Watermarking Scheme

The basic idea of watermarking is to add a watermark signal into the host data to be watermarked such that the watermark signal is secure in the signal mixture, but can partly or fully be recovered from the signal mixture later on if the correct cryptographically secure key is used.

In order to ensure robustness, the watermark information is distributed redundantly over many samples of the host data. Therefore, the recovery is more robust if more watermarked data are available for recovery.

In general, watermark systems use one or more cryptographically secure keys to ensure security against manipulation and erasure of the watermark. The embedding process of a generic watermarking scheme is shown in Figure 1.

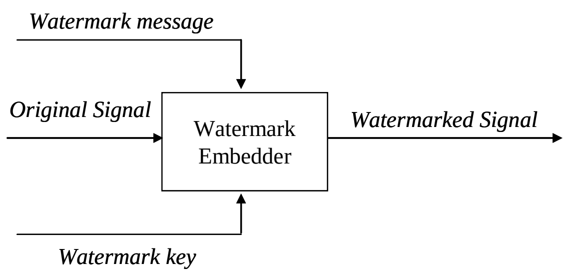

Figure 1: Watermark Embedding Process

The input to the scheme is the watermark, the host data, and an optional public or secret key. Depending on applications, the host data may be uncompressed or compressed; however, most of the methods work on uncompressed data. The watermark can be of any nature, such as a number, a text, or an image. The secret or public key is used to enforce security. If the watermark is not to be read by unauthorized parties, a key can be used to protect the watermark, in combination with a secret or public key, watermarking techniques are usually referred to as secret and public watermarking techniques, respectively. The output of the watermarking scheme is the watermarked data.

The detection process of a generic watermarking scheme is shown in Figure 2. Inputs to the scheme are the attacked watermark data, the secret or public key, and the original data or the original watermark depending on the method. The output of the watermark recovery process is either the recovered watermark or some kind of confidence measure indicating how likely it is for the given watermark at the input to be present in the data under inspection.

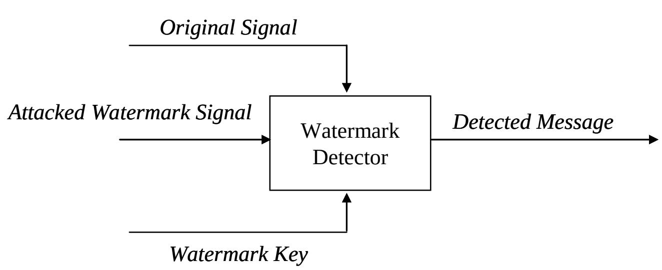

Figure 2: Watermark Detection Process

Many watermarking schemes employ ideas borrowed from spread spectrum communications. They embed a watermark by adding pseudo-random sequences of low amplitude to the host data. The specific pseudo-random sequences can be detected using a correlation receiver or a matched filter. If the added pseudo-random sequence is chosen appropriately, the probability of false alarm is very low.

4. Proposed Watermarking Scheme

A watermark must not be embedded into insignificant region of the audio signal because many common signal processing attacks affect these components. For example, if a watermark is embedded in the high frequency spectrum of an audio signal, low-pass filtering can easily eliminate the watermark. Thus, it is very important to find the significant regions and embed a watermark into those regions without distortion of the original audio signal.

In this section, we give an overview of our basic watermarking scheme which consists of watermark embedded process and watermark detection process. In this implementation, a watermark consists of a sequence of real numbers X= {x1, x2, x3,..., xn}. We create a watermark where each value of xi is chosen independently according to N(0,1) where $N(\mu, \sigma^2)$ denotes a normal distribution with mean μ and variance σ^2.

4.1. Watermark Embedding Process

The proposed watermark embedding process is shown in Figure 3. The embedding process is implemented in the following seven steps:

1. The original audio is first segmented into non-overlapping frames.
2. Calculate the magnitude and phase spectrum of each frame using fast Fourier transform (FFT).
3. Find the n most prominent peaks **V**= $\{v_1, v_2, v_3, ..., v_n\}$ from magnitude spectrum using a peak detection algorithm.
4. Place watermarks into the n prominent peaks of magnitude spectrum to obtain watermarked peaks **V'=** $\{v_1', v_2', v_3', ..., v_n'\}$. This ensures that the watermark is located at the most significant perceptual components of the audio. When we insert the watermark X into V to obtain V', we specify a scaling parameter α, which determines the extent to which X alters V, shown in the equation (1) [10].
5. Insert back the n modified peaks into the magnitude spectrum of each non-overlapping frame.
6. Take an inverse FFT of the complex spectrum to calculate the watermarked frame.
7. Finally concatenates all watermarked frames to calculate the watermarked audio signal.

4.2. Watermark Detection Process

The proposed watermark detection process is shown in Figure 4. The detection process is implemented in the following three steps:

1. Calculate the FFT of the attacked watermark audio frame.
2. Extract n peaks from the magnitude spectrum which are located at the same position in the embedding process above.

3. Extract the watermark sequence by performing the inverse operation of (1) represented by the equation (2).

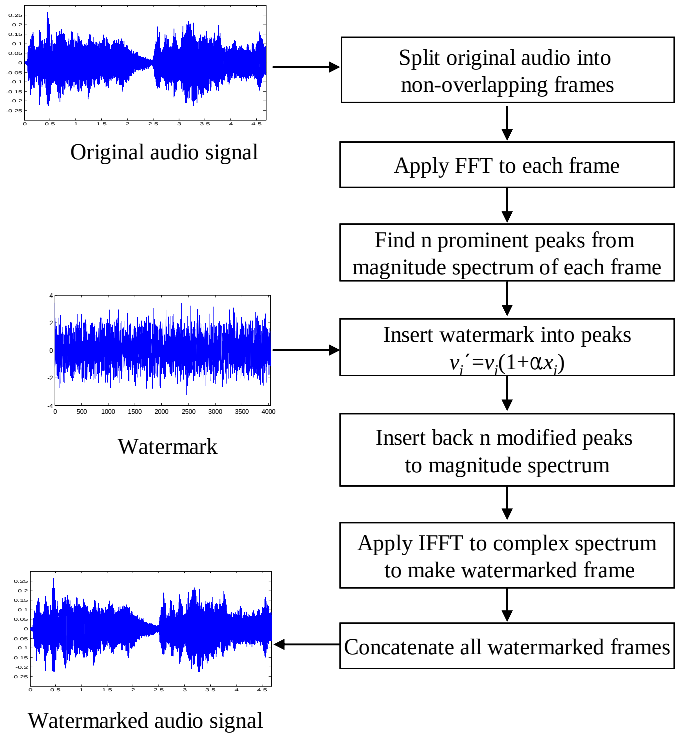

Figure 3: Proposed Watermark Embedding Process

5. Simulation Results and Discussions

In this section, we evaluate the performance of our watermarking scheme using four different types of 16 bit mono audio signals sampled at 44.1 kHz: (a) ‘Let it be’ written by Beatles; (b) ‘the beginning of the Symphony No. 5 in c minor, Op. 67’, written by Ludwig van Beethoven; (c) an instrumental song ‘Hey Jude’ played by a Korean traditional musical instrument called the Gayageum; (d) a human voice providing TOEIC listening test instruction. Each audio file contains 206,336 samples (duration 4.679 sec). By considering the frame size of 512 samples, we have 403 frames for each audio sample. From each frame we detect 10 peaks to embed watermark. Thus, the length of the watermark sequence is 10×403=4,030.

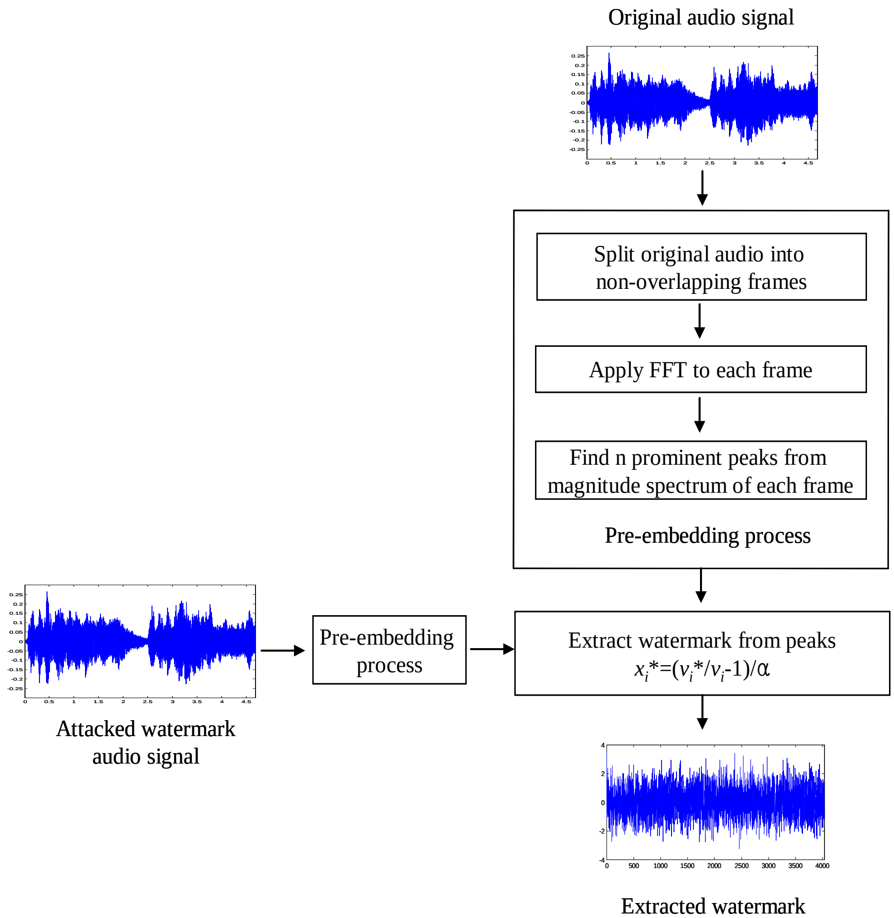

Figure 4: Proposed Watermark Detection Process

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

$$SIM(X, X^*) = \frac{X \cdot X^*}{\sqrt{X^* \cdot X^*}} \tag{3}$$

It is highly unlikely that X^* will be identical to X. To decide whether X and X^* match, we determine whether the SIM(X, X^*) > T, where T is a detection threshold. In this study, the selected detection threshold (T) value is 6 [10].

Figure 5 shows a qualitative evaluation of the original audio with a watermarked audio in which the watermarks are imperceptible using the proposed scheme.

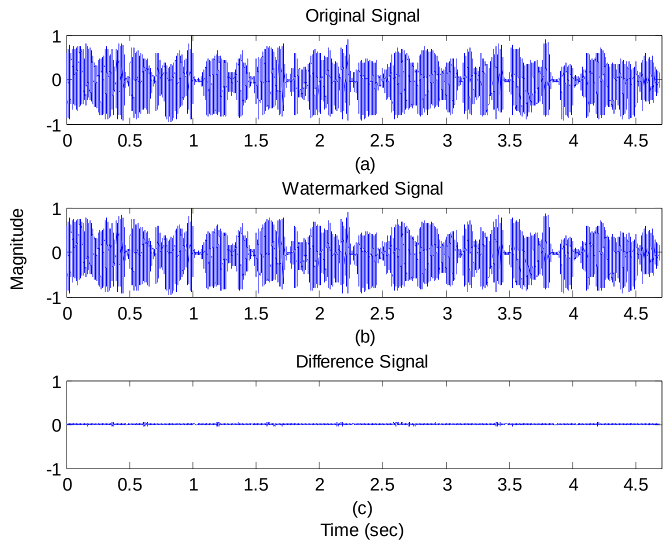

Figure 5: Imperceptibility of the Watermarked Audio Using the Proposed Method: (a) Original Human Voice Sound, (b) Watermarked Human Voice Sound (c) Difference between Original and Watermarked Human Voice Sound

In order to evaluate the quality of watermarked signal, the following signal-to-noise ratio (SNR) equation is used:

$$SNR = 10\log_{10}\frac{\sum_{n=1}^{N} S^2(n)}{\sum_{n=1}^{N}\left[S(n) - S^*(n)\right]^2} \tag{4}$$

where S(n) and $S^*(n)$ are original audio signal and watermarked audio signal respectively. After embedding watermark, the SNR of all selected audio signals using the proposed method are above 20 dB which ensures the imperceptibility of our proposed scheme.

Figure 6 shows the peak detection of first frame of human voice sound. In our proposed scheme, watermarks are embedded into the selected prominent peaks of the magnitude spectrum of each frame which provides high robustness against different kinds of attacks as well as good SNR values for watermarked audio signals.

In Cox's method, on the other hand, watermarks are embedded into the higher DCT coefficients of the whole sound excluding the DC component. Figure 7 shows the highest 4030 DCT coefficients of the human voice sound in which watermarks are embedded.

Table 1 shows the SNR comparison between the proposed watermarking scheme and Cox's method for different values of α. Our proposed scheme achieves SNR values ranging from 20 dB to 28 dB for different watermarked sounds. This is in contrast to Cox's method which achieves SNR values ranging from only 14 to 23. In other words, our proposed watermarking scheme provides 6 dB higher SNR values than Cox's method for different watermarked sounds. Thus, our proposed watermarking scheme outperforms Cox's method in terms of imperceptibility.

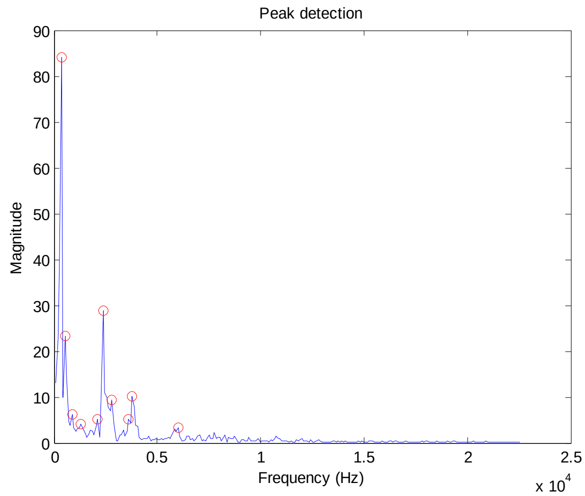

Figure 6: Peak Detection in Frequency Spectrum

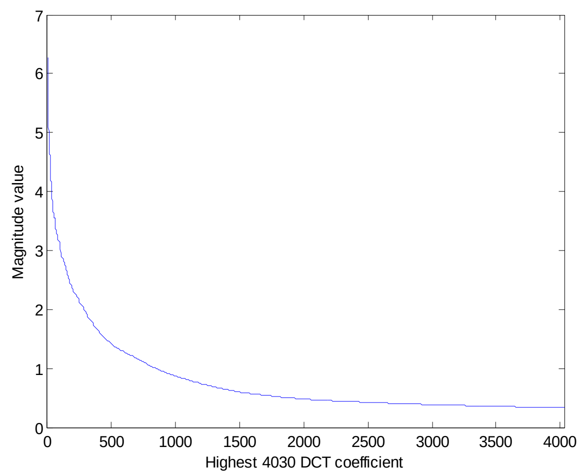

Figure 7: DCT Coefficients for Human Voice Sound

Table 1: SNR Comparison between Proposed Scheme and Cox's Method

Types of Signal	Cox	Proposed	Cox	Proposed	Cox	Proposed
	α=0.1		α=0.2		α=0.3	
Let it be	23.561	25.654	17.586	23.176	14.067	20.202
Symphony No 5	23.772	27.395	17.611	23.652	14.089	20.649
Hey Jude	23.741	27.218	17.668	23.843	14.146	20.776
Human Voice	23.786	28.259	17.968	24.163	14.446	20.779

5.1 Imperceptibility Test

Informal listening using head set reveals that the watermark embedded into the original audio using the proposed watermarking scheme does not affect the quality of the sound, which ensures imperceptibility of the embedded watermark.

5.2 Robustness Test

Table 2 shows the performance comparison in terms of similarity between the proposed scheme and Cox's method when no attack is applied to four different types of watermarked audio signals for α=0.3. The proposed method is comparable with Cox's method [10] in terms of similarity.

Table 2: Watermark Detection Result of the Proposed Scheme and Cox's Method.

Types of signal	SIM	
	Proposed	Cox
Let it be	64.6345	64.9933
Symphony No 5	64.4371	64.9933
Hey Jude	64.5267	64.9932
Human Voice	64.2483	64.9933

Figures 8 and 9 show the response of the watermark detector to 1000 randomly generated watermarks where correct watermark is at the 500th position when no attack is applied to the watermarked human voice sound using proposed scheme and Cox's method respectively.

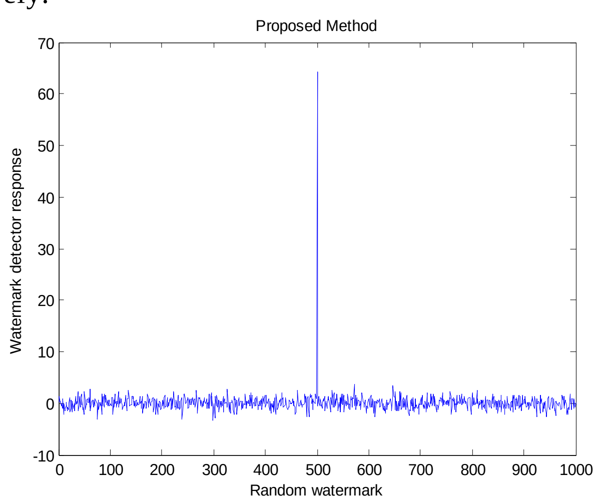

Figure 8: Response of Watermark Detector for Watermarked Human Voice Sound using Proposed Method

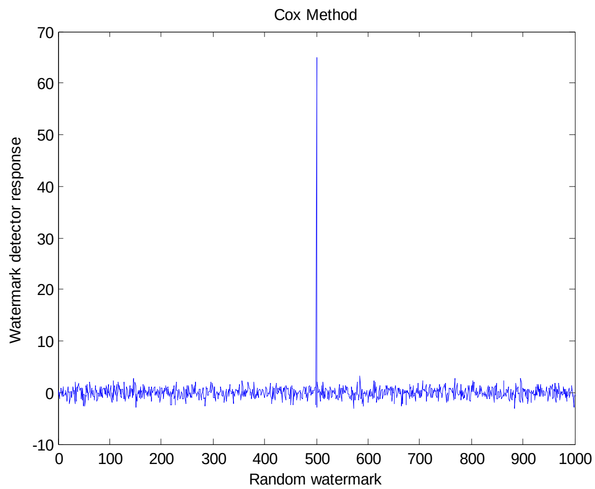

Figure 9: Response of Watermark Detector for Watermarked Human Voice Sound using Cox's Method

In order to test the robustness of our proposed scheme, six different types of attacks, summarized in Table 3, were performed to the watermarked audio signal.

Figures 10 and 11 show the response of the watermark detector to 1000 randomly generated watermarks where correct watermark is at the 500th position against Gaussian noise attack for α=0.3 using the proposed scheme and Cox's method.

Table 3: Attacks Used in this Study for Watermarked Sound

Attacks	Description
Noise addition	Additive white Gaussian noise (AWGN) is added with the watermarked audio signal.
Cropping	We removed 10% samples from the beginning of the watermarked signal and then replaced these samples by the original signal.
Re-sampling	The watermarked signal originally sampled at 44.1 kHz is re-sampled at 22.050 kHz, and then restored by sampling again at 44.1 kHz.
Re-quantization	The 16 bit watermarked audio signal is quantized down to 8 bits/sample and again re-quantized back to 16 bits/sample.
MP3 Compression	MPEG-1 layer 3 compression with 128 kbps is applied to the watermarked signal.
Low-pass filtering	The low-pass filter used in this study is a second order Butterworth filter with cut-off frequency 10 kHz.

Tables 4, 5, 6, and 7 shows the similarity results of the proposed scheme and Cox's method in terms of robustness for different values of α against several kinds of attacks applied to four different types of watermarked audio signal 'Let it be', 'Symphony No 5', 'Hey Jude', and 'human voice' respectively.

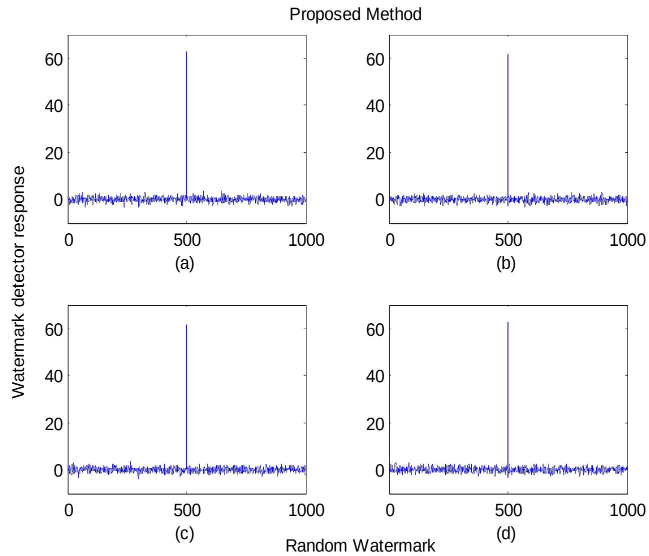

Figure 10: Watermark Detector Response Against Gaussian Noise Attack Using the Proposed Method: (a) Let it be, (b) Symphony No. 5, (c) Hey Jude, (d) Human Voice

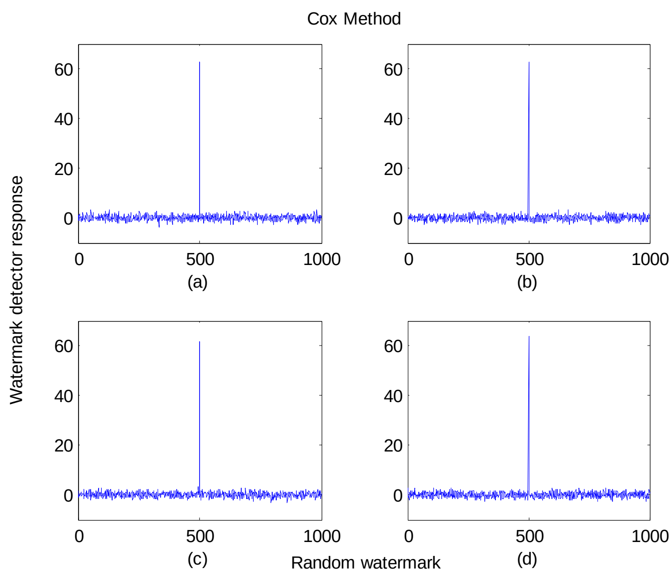

Figure 11: Watermark Detector Response Against Gaussian Noise Attack Using the Cox Method: (a) Let it be, (b) Symphony No. 5, (c) Hey Jude, (d) Human Voice

Table 4: Similarity Results of the Proposed Scheme and Cox's Method Against Different Attacks for the Signal 'Let It Be'

Types of Signals	Cox	Proposed	Cox	Proposed	Cox	Proposed
	α= 0.1		α= 0.2		α= 0.3	
Noise addition	62.195	61.913	62.726	62.325	62.937	62.538
Cropping	58.729	55.652	59.237	57.824	60.462	59.372
Re-sampling	64.989	62.555	64.990	63.543	64.992	63.846
Re-quantization	64.772	62.286	64.875	63.725	64.923	63.948
MP3 Compression	63.524	58.735	63.897	60.247	63.927	62.357
Low-pass filtering	61.514	58.511	61.625	60.725	61.826	61.436

Table 5: Similarity Results of the Proposed Scheme and Cox's Method Against Different Attacks for the Signal 'Symphony No 5'

Types of Signals	Cox	Proposed	Cox	Proposed	Cox	Proposed
	α= 0.1		α= 0.2		α= 0.3	
Noise addition	62.314	60.481	62.723	61.317	62.942	61.424
Cropping	57.961	59.493	58.627	60.527	59.266	61.478
Re-sampling	64.993	63.790	64.993	63.815	64.993	63.936
Re-quantization	64.993	63.921	64.993	63.957	64.993	63.983
MP3 Compression	60.512	57.352	61.726	59.528	62.268	60.674
Low-pass filtering	59.623	57.272	60.216	59.632	60.583	60.215

Table 6: Similarity Results of the Proposed Scheme and Cox's Method Against Different Attacks for the Signal 'Hey Jude'

Types of Signals	Cox	Proposed	Cox	Proposed	Cox	Proposed
	α= 0.1		α= 0.2		α= 0.3	
Noise addition	59.619	59.805	60.347	60.528	61.413	61.725
Cropping	57.287	58.737	58.376	59.419	59.269	60.348
Re-sampling	64.983	61.977	64.993	62.576	64.993	62.865
Re-quantization	62.182	59.103	62.746	60.214	62.876	60.795
MP3 Compression	63.492	58.413	63.872	60.528	63.945	61.213
Low-pass filtering	60.736	59.898	60.917	60.637	61.527	61.357

Table 7: Similarity Results of the Proposed Scheme and Cox's Method Against Different Attacks for the Signal 'Human Voice'

Types of Signals	Cox	Proposed	Cox	Proposed	Cox	Proposed
	α= 0.1		α= 0.2		α= 0.3	
Noise addition	63.626	61.018	63.728	62.218	63.923	62.735
Cropping	59.760	56.468	60.246	58.583	61.372	59.672
Re-sampling	61.642	60.238	62.357	61.567	62.893	61.784
Re-quantization	63.933	61.072	64.215	62.136	64.637	62.538
MP3 Compression	61.506	57.682	61.927	59.258	62.535	60.385

Overall, our proposed watermarking scheme outperforms Cox's method in terms of SNR values for different watermarked sounds. In addition, it provides similar robustness with Cox's method against several attacks such as noise addition, cropping, re-sampling, re-quantization, MP3 compression, and low-pass filtering.

6. Conclusion

In this paper, a new watermarking algorithm based on Fast Fourier Transformation for audio copyright protection has been presented. Simulation results indicate that our proposed watermarking scheme outperforms Cox's method in terms of imperceptibility while maintaining comparable robustness with Cox's method against several kinds of attacks such as noise addition, cropping, re-sampling, re-quantization, MP3 compression, and low-pass filtering. Our proposed method achieves SNR values ranging from 20 dB to 28 dB for different watermarked sounds. This is in contrast to Cox's method which achieves SNR values ranging from only 14 dB to 23 dB. These results demonstrate that our proposed watermarking scheme can be a suitable candidate for copyright protection of audio signal.

References

[1] W. N. Lie and L. C. Chang, "Robust and High-Quality Time-Domain Audio Watermarking Based on Low-Frequency Amplitude Modification," IEEE Transaction on Multimedia, vol. 8, no. 1, pp. 46-59, February, 2006.

[2] P. Bassia, I. Pitas and N. Nikolaidis "Robust Audio Watermarking in the Time domain," IEEE Transaction on Multimedia, vol. 3, no. 2, pp. 232-241, June, 2001.

[3] L. Xie, J. Zhang and H. He, "Robust Audio Watermarking Scheme Based on Nonuniform Discrete Fourier Transform," in Proceedings of IEEE International Conference on Engineering of Intelligent System, pp. 1-5, 2006.

[4] G. Zeng and Z. Qiu, "Audio Watermarking in DCT: Embedding Strategy and Algorithm," in Proceedings of 9th International Conference on Signal Processing (ICSP'09), pp. 2193-2196, 2008.

[5] J. Huang, Y. Wang, and Y. Q. Shi, "A Blind Audio Watermarking Algorithm with Self-Synchronization," in Proceedings of IEEE International Symposium on Circuits and Systems, (ISCAS'02), vol. 3, pp. 627–630, 2002.

[6] M. Pooyan and A. Delforouzi, "Adaptive and Robust Audio watermarking in Wavelet Domain," in Proceedings of International Conference on International Information Hiding and Multimedia Signal Processing (IIH-MSP 2007), vol. 2, pp. 287-290, 2007.

[7] X. Y. Wang, H. Zhao, "A Novel Synchronization Invariant Audio Watermarking Scheme Based on DWT and DCT," IEEE Transaction on Signal Processing, vol. 54, no. 12, pp 4835-4840, December 2006.

[8] S. K. Lee and Y. S. Ho, "Digital Audio Watermarking in the Cepstrum Domain," IEEE Transactions on Consumer Electronics, vol. 46, no. 3, pp. 744–750, 2000.

[9] S. C. Liu and S. D. Lin, "BCH Code Based Robust Audio Watermarking in the Cepstrum Domain," Journal of Information Science and Engineering, vol. 22, pp. 535–543, 2006.

[10] I. Cox, J. Killian, F. Leighton, and T. Shamoon, "Secure Spread Spectrum Watermarking for Multimedia," IEEE Transactions on Image Processing, vol. 6, no. 12, pp. 1673-1687, 1997.

Authors

Pranab Kumar Dhar received the B.S. degree in Computer Science and Engineering from Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh in 2004. He received M.S. degree from the School of Computer Engineering and Information Technology at University of Ulsan, South Korea in 2010. Since 2005, he has been serving as a faculty member in the Department of Computer Science and Engineering at Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh. His research interest includes Digital Watermarking, Sound Synthesis, Digital Image Processing, Multimedia Systems, and Digital Signal Processing.

Jong-Myon Kim received the B.S. degree in Electrical Engineering from Myongji University, South Korea in 1995. He received M.S. degree from the School of Electrical and Computer Engineering at University of Florida, Gainesville, FL, USA in 2000. He received his Ph.D. degree from the School of Electrical and Computer Engineering at Georgia Tech, Atlanta, GA in 2005. Currently he is a faculty member in the School of Computer Engineering and Information Technology at University of Ulsan, South Korea. His research interest includes high performance, energy efficient computer architectures, application specific SOC design for embedded color image and video processing, Digital Watermarking, Sound Synthesis, Multimedia Systems, and Digital Signal Processing. Prior to joining academia, he was a processor architect in both multi-format CODEC chip design and prototyping team and reconfigurable processor team at Samsung Advanced Institute of Technology (SAIT), South Korea. He is actively participating as a member of different professional research societies, like IEEE, KIPS, KIISE, KSCI, and EASCO.