Section A-Research paper
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IMPROVED AUDIO WATERMARKING USING WEIGHT ADJUSTED GRAPH BASED TRANSFORM (WA – GBT)

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Abstract

In the growth of Transforms such as Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), Graph Based Transform (GBT) has its steps in signal processing applications. In this paper, the weights of the edges in GBT are adjusted to form an improved GBT. The improved GBT is implemented in audio watermarking. The proposed method is tested on NOIZEUS speech database and MIR1k music database and proved that the improved GBT outperforms its base GBT method against various attacks. Also, the quality of the audio signal is measured after watermarking using Peak Signal to Noise Ratio (PSNR), Short-Time Objective Intelligibility (STOI) and Perceptual Evaluation of Speech Quality (PESQ). The proposed method obtains appreciable results than its base GBT method.

Keywords: watermark, attack, Graph-based Transform, Adjacency Matrix

I. Introduction

Information is concealed through the act of embedding a message in digital media. The embedded message should be inaudible or invisible. The primary medium should also continue to be original. To put it another way, the message shouldn't actually alter the primary media [1]. Steganography and watermarking are two methods of information concealment. Steganography's basic objective is to conceal the communication principle.

Only the receiver can decode a serial message that the transmitter has embedded in a digital medium (like audio).

Given that both steganography and watermarking attempt to conceal the information, they are rather comparable. However, steganography uses point-to-point communication between two parties. As a result, formatting, or even analog to digital conversion may have an impact on the sent signal, and steganography often has a limited resilience to these effects. Watermarking, in comparison, follows distinct guidelines. If someone has access to media (such as audio or images) and they are aware that it contains some concealed information, they may embellish to gain access to that information. Thus, in watermarking, the question of defending against assaults is crucial.

The applications of watermarking include Copyright Protection, Markup and Content Authentication [2-5]. This tool allows us to determine whether a digital file has been altered. However, the approaches and uses of watermarking discussed in past research have been more focused on images, with less consideration given to the audio contents. Researchers' interest in graph-based signal processing approaches has recently increased. The graph-oriented conversion is a graphical processing program that is frequently used to compress data [6, 7].

The growth of transforms has its footsteps in every domain such as video compression [8], audio compression [9], watermarking etc. The impact of wavelet transform is studied in [8]. Graph-based Transform is a method for audio compression that is documented in [9], which recommends this method above a well-liked traditional method, specifically DCT. The primary goal of this study is to employ this technique to add watermark data to audio signal segments that can withstand compression. When the watermark data is included with the signal's essential components, it nearly never becomes corrupted via compression, format changes, or additive noise. This work develops a graph-based modification approach for an audio signal that increases the watermarking's resistance to different assaults.

The main contributions of the paper include:

- ❖ Graph Based Transform is used for embedding and extracting watermark image.
- ❖ Instead of randomly choosing segments for watermarking, the segments with high energy coefficients are selected for embedding.
- ❖ The weights of the adjacency matrix are adjusted to nearer edges in the GBT graph.

The remaining of the paper is organized as follows: Section 2 gives the recent works in audio watermarking. Section 3 elaborates the proposed method with clear algorithms and architecture. Section 4 discusses and analyses experimental results of the proposed method. Section 5 concludes the work and gives its future scope.

II. Literature Review

The method designed in [9] is integrated in [10] to improve the efficiency of audio watermarking against different attacks. A secure watermarking approach is given in [11] and is based on the embedding of the audio signal in the DWT of the audio data. By determining the appropriate amount of DCT coefficients is retained, the audio datal to be embedded is compressed using DCT. Instead of sequential embedding, the chaotic map is utilized to pick the cover audio segments at random. The DCT coefficients of the audio data are inserted in the singular matrix after the audio is decomposed using DWT and Singular Value Decomposition (SVD).

DWT and chaotic signal-based speech signal compression and encryption has been introduced in [12]. The voice signal is compressed and coded using DWT for wavelet coefficients. To lessen the amount of data, the less significant coefficients are deleted. The residual coefficients are then proposed to be encoded using a novel coding method that makes use of chaotic signals. The suggested technique employs four connected Hènon Chaotic Maps (HCM) to achieve a high level of encryption strength.

The embedded use of unencrypted watermarks readily compromises security, and the existing audio watermarked data based on DWT confront robustness difficulties pertaining to external assaults. Additionally, the competing watermarking characteristics of embedding capacity and imperceptibility could not be reconciled by these approaches. A strong two-fold audio watermarking system has been created as a workaround that initially takes use of the binary image using Bose-Chaudhuri-Hocquenghem codes and Arnold encryption [13]. By using this technique, the security of the watermark image is improved since hackers cannot directly extract the watermark data. Before watermarking, dual-tree complex wavelet transformations, short-time Fourier transforms and SVD are used to decompose both encrypted image and host audio.

By utilizing the Fuzzy Inference System (FIS), SVD, and Fibonacci series in DCT, a novel audio watermarking system is shown in [14]. This method is transparent and robust. By assisting the FIS with energy, it identifies appropriate segments for introducing watermark data during the embedding phase. Then, using a combination of the SVD approach and the Fibonacci series in the DCT domain, the watermark bits are implanted in the appropriate segments.

Limited payload and low resilience against typical audio watermarking and assaults, particularly attack, are the fundamental drawbacks of the current DCT and DWT technologies. The Dual Tree Complex Wavelet Transform (DTCWT) and the Fractional Charlier Moment Transform (FrCMT) are used to provide an efficient audio watermarking system in [15]. The 3-level DTCWT is applied on original audio signal using filters which are followed by the application of FrCMT. Finally, FrCMT coefficients are quantized to create a sequence of watermark bits. FrCMT's fractional order is selected to achieve excellent resilience and imperceptibility against the majority of typical audio processing operations and assaults. Additionally, it serves as a security key to guarantee the method's high level of security. This approach attests to its great resilience, security, and effectiveness.

Another technique in [16] combines DWT and ensemble-intelligent extraction strategy by combining learned classifiers to address the shortcomings of traditional methods and basic intelligent approaches and enhances the performance. The DWT and the difference in energy levels generated from DWT coefficients are employed for the embedding operation in the suggested technique.

A first digital watermarking scheme has been developed in [17] for copyright protection, where neural network is used. Along with the linear predictive coding of the audio data, several masking phenomena from the human psychoacoustic model are also utilised. In terms of imperceptibility and resilience, experiments demonstrated the effectiveness of this

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method. Additionally, a second audio watermarking method based on deep learning classification architecture has been developed for non-security content characterisation applications. The extracted watermark in this approach provides information on the audio data, speaker gender, and emotion.

Based on DCT and SVD, a reliable and nearly undetectable audio watermarking technique is provided [18]. The low-frequency components of the audio signal have been carefully chosen to be selectively incorporated with watermark picture data, resulting in highly resilient and invisible watermarked audio.

Two well-known transforms, including DWT and SVD, are employed in [19]. Different levels of resilience against assaults using watermarks are offered by the two transformations. Major benefits of this strategy are the dispersed wavelet coefficient matrix creation and the use of the singular value matrix's off-diagonal locations.

A genetic algorithm-based audio watermarking system with a high payload that is perceptually transparent and reliable is given [20]. This method uses a genetic algorithm to determine the ideal amount of audio samples needed to conceal each watermarking bit. The wavelet domain's undetectable LU (Lower Upper) factorization is used for the embedding.

Based on the unique characteristics of Multilevel DWT (MDWT) and DCT, a self-synchronizing blind audio watermarking approach has been created [21]. In this technique, the wideband signal covering the first to tenth detail sub-bands is utilized to hide binary information, and the repeated pattern hidden in the 11th approximation sub-band is employed to manage frame synchronization.

SVD-based schemes and their susceptibility to FPP are studied in [22]. Segments of audio are separated. Each audio segment is altered using the Integer Wavelet Transform (IWT), and the Arnold modified watermark is then subjected to SVD. Using the product of a singular vector matrix and a singular values matrix, the Principal Component (PC) is produced. The watermark image on the computer is used to modify the transformed audio.

To fend against recapturing attempts, another audio watermarking system built on the Frequency Domain Power Spectrum (FDPS) feature has been created [23]. A lengthy audio transmission is split into fragments after being separated into pieces. By quantifying the feature produced by DWT coefficients, synchronization codes are encoded in some pieces. Synchronization codes are taken from the incoming audio in order to find the watermarked pieces and subsequently extract the copyright information.

III. Proposed Improved GBT Methodology

The conventional watermarking architecture consists of embedding and extraction process. In this method, the same process is done in which the watermark image is embedded in audio signal. The embedding process should not reduce the quality of the signal and the extraction process should extract the absolute watermark image. The proposed system architecture is shown in Fig. 1. In the embedding process, the most important part of the signal is identified to embed the watermark image. As this part remain unchanged in compression.

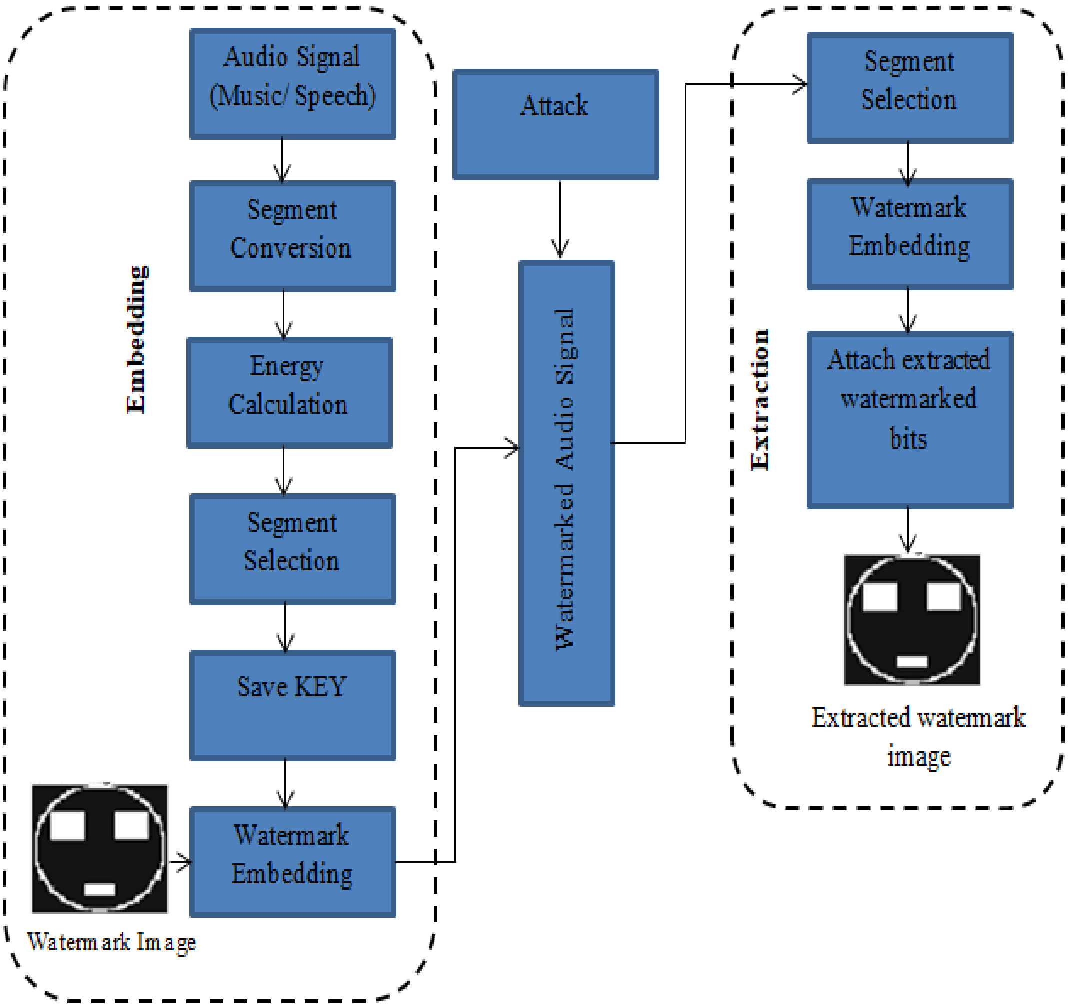

Fig. 1 Architecture of the Proposed System

Initially, the audio signal is divided into segments of fixed size. The segment with highest energy is selected. This is done by calculating the energy of each segment which is then sorted in ascending order. The last few segments are selected for embedding. The size of the selected segment depends on the size of the watermark image. The index of the selected segments are stored as KEY for further processing. The watermark image is then embedded in the selected segments using improved GBT method. The other segments are concatenated to form the watermarked image. In the extraction phase, the watermark image is extracted by the same process in reverse order. An appropriate graph structure of audio signal is given in [9].

Given an image of size N, a graph is created as $G = \{V, E\}$, where V and E are the vertices and edges of the graph. For this graph, the adjacency matrix is created as

$$A_{ij} = \begin{cases} a_{ij} & if(i,j) \in E \\ 0 & otherwise \end{cases} \quad (1)$$

Where a_{ij} is the weight of the edge between i and j in the graph. This weight is assigned in such manner that the nearest edge is assigned 1 and it is decreased by 0.25 for the subsequent edges. The adjacency matrix of graph structure of size 10 will look like the one shown in Eq. 2.

$$A=\begin{bmatrix} 0 & 1 & 0.75 & 0.5 & 0.25 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0.75 & 0.5 & 0.25 & 0 & 0 & 0 & 0 \\ 0.75 & 1 & 0 & 1 & 0.75 & 0.5 & 0.25 & 0 & 0 & 0 \\ 0.5 & 0.75 & 1 & 0 & 1 & 0.75 & 0.5 & 0.25 & 0 & 0 \\ 0.25 & 0.5 & 0.75 & 1 & 0 & 1 & 0.75 & 0.5 & 0.25 & 0 \\ 0 & 0.25 & 0.5 & 0.75 & 1 & 0 & 1 & 0.75 & 0.5 & 0.25 \\ 0 & 0 & 0.25 & 0.5 & 0.75 & 1 & 0 & 1 & 0.75 & 0.5 \\ 0 & 0 & 0 & 0.25 & 0.5 & 0.75 & 1 & 0 & 1 & 0.75 \\ 0 & 0 & 0 & 0 & 0.25 & 0.5 & 0.75 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0.25 & 0.5 & 0.75 & 1 & 0 \end{bmatrix} \quad (2)$$

In the above matrix, the weight between vertices (1, 2) is assigned 1, whereas for (1, 3), (1, 4) and (1, 5), it is assigned as 0.75, 0.5 and 0.25 respectively. The diagonal matrix for the given adjacency matrix A is given as

$$D = \begin{cases} \sum w_{ij} & if\ i = j \\ 0 & otherwise \end{cases} \quad (3)$$

Where w_{ij} is the element of adjacency matrix A. The algorithm of the Weight Adjusted GBT Method (WA – GBT) is given in Algorithm 1.

The diagonal matrix for A is given as

$$D=\begin{bmatrix} 5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 9.5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 10 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 9.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 7 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 5 \end{bmatrix} \quad (4)$$

Then the Laplacian Matrix is created as

$$L = D - A \tag{5}$$

The Eigen values are computed for L. The obtained eigen vectors are multiplied with the selected segments. The Singular Valued Decomposition (SVD) is applied to the obtained segments. This decomposition provides the largest singular value (s). The watermark bit is embedded into this bit.

Algorithm 1: WA - GBT Method

Input: Segment_Size
Output: Adjacency Matrix A
Steps:

1. persv = 0.4
2. ***For*** i = 1 : Segment_Size
   2.1 ***For*** j = 1 : Segment_Size
      2.1.1 ***If*** abs(i - j) = 1
         A(i, j) = 1
      2.1.2 ***Else If*** abs(i - j) = 0
         A(i, j) = 0
      2.1.3 ***Else If*** abs(i - j) <= Segment_Size * persv
         A(i, j) = 1- (abs(i - j) - 1) * (1 / (Segment_Size * persv))
      2.1.4 ***Else***
         A(i, j)=0
      2.1.5 ***End***
   2.2 ***End***
3. ***End***

The entire algorithm for embedding watermark image is given in Algorithm 2. The inputs to this algorithm are audio signal, watermark image and watermark strength.

Algorithm 2: Embedding

Input: Audio Signal, Watermark Image, Watermark Strength WS
Output: Watermarked_Audio, KEY, σ
Steps:

1. Divide audio signals into segments $frames = S_1, S_2, \dots, S_n$
2. ***For*** each segment
   2.1 Calculate Energy E
3. ***End***
4. Sort E
5. Select the segments of Watermark Image size with highest E
6. Assign the selected segments index as KEY
7. Create Adjacency Matrix A of Segment size using Algorithm 1
8. Calculate Diagonal Matrix D using Eq. (3)

9. Create Laplacian Matrix $L = D - A$
10. Calculate Eigen values $EV = Eigen(L)$
11. ***For*** each i in KEY
    11.1 $F = frames(i) \times EV$ramesi×EV
    11.2 $[u\ s\ v] = SVD(F)$
    11.3 $\sigma(i) = s(1)$
    11.4 ***If*** $Watermark_{bit} = 1$
    $s(1) = \sigma(i) + WS$
    11.5 ***Else if*** $Watermark\_bit = 0$
    $s(1) = \sigma(i) - WS$
    11.6 ***End***d
    11.7 F_2=Inverse SVDF
    11.8 $InvF = F_2/EV$
    11.9 $frames(i) = InvF$mesi=InvF
12. ***End***
13. Add all the remaining segments to create Watermarked_Audio

In the above algorithm, σ represents the largest singular decomposition. The watermarked audio is got as output from the above algorithm. The embedded watermarked image can be extracted using the Algorithm 3. The inputs to this algorithm are the watermarked audio, KEY and σ which are obtained from Algorithm 2.

Algorithm 3: Extraction

Input: Watermarked Audio, KEY, σ

Output: Extracted Watermark Image

Steps:

1. Divide Watermarked Audio into segments $Wframes = S_1, S_2, \ldots, S_n$
2. Do Steps 1, 7, to 10 in Algorithm 2.
3. ***For*** each i in KEY
    1.1 $F = Wframes(i) \times EV$
    1.2 $[u\ s2\ v] = SVD(F)$
    1.3 $s = \sigma(i)$
    1.4 ***if*** $s2(1) > s$
    Extracted_Watermark=1
    1.5 End
4. **End**

We obtain the extracted watermark image from the above algorithm with the same process as in embedding.

IV. Experimental Results

The proposed improved GBT based audio watermarking is experimented on NOIZEUS speech [24] and MIR-1k music database. The former consists of 15 male voices and 15 female voices while the latter consists of 1000 pop music. The quality of the watermarked audio signal is evaluated using PSNR and STOI [25]. These measurements are taken with for 10 audiences between input audio signal and the watermarked audio signal. The extracted watermark images are evaluated using Bit Error Rate (BER).

High PSNR and low BER during attacks are characteristics of a good watermarking system. The 10 audiences were asked to evaluate the audio signals on a scale of 1 (very unpleasant) to 5 (no sensation of change), while also listening to the original and watermarked versions. To test the resistance of the proposed approach, we simulated 8 different attacks, including Additive White Gaussian Noise (AWGN), MP3 compression, Low Pass Filtering (LPF), High Pass Filtering (HPF), re-sampling, requantization, Amplitude Scaling (AS), and cropping.

The SNR levels for the AWGN assaults in our experiments are 20dB and 10dB. The MP3 compression bitrates are 64 kbps and 32 kbps. LPF and HPF have cutoff frequencies of 4 kHz and 50 Hz, respectively. We downsample and then upsample the watermarked signal during the resampling assault. The scaling coefficient for the AS attack is 0.7, and the thresholds for quantization are 24 and 8. 20% and 30% of the audio signal are cropped out at the beginning of the transmission for this assault. The outcomes of the suggested procedure are shown in Table 1 following the embedding of the watermark image.

Table 1 Average Measures between Input and Watermarked Audio

Method	PSNR	STOI
GBT	44.104	0.9406
Proposed WA – GBT Method	46.109	0.96161

In Table 1, the proposed WA - GBT achieves very less error rate when compared to its base model with very high PSNR. Table 2 shows the BER of the proposed method and the existing GBT method obtained for speech.

Table 2 BER Obtained by the Proposed Method and Existing GBT Method on Speech

Attack	GBT on Speech	Proposed Method on Speech
No attack	0	0
AWGN(20 db)	0	0
AWGN(10 db)	0	0
Re-sampling(6000)	0	0
Re-sampling(4000)	0.011	0.003
LPF (4 kHz)	0	0
HPF (50 Hz)	0	0
AS(0.9)	0.02	0.01
AS(0.7)	0.415	0.301

Re-quantization(24)	0	0
Re-quantization(8)	0.07	0.02
Cropping(20%)	0.107	0.092
Cropping(30%)	0.185	0.103
Average	**0.063**	**0.041**

From Table 2, it is observed that the proposed WA - GBT method is very prune to various attacks. There is a reduction of 0.02 in average BER obtained by the proposed method. Table 3 displays the BER obtained for music.

Table 3 BER Obtained by the Proposed Method and Existing GBT Method on Music

Attack	GBT on Music	Proposed Method on Music
No attack	0	0
AWGN(20 db)	0	0
AWGN(10 db)	0.06	0.042
Re-sampling(6000)	0	0
Re-sampling(4000)	0	0
LPF (4 kHz)	0	0
HPF (50 Hz)	0.09	0.051
AS(0.9)	0.46	0.403
AS(0.7)	0.46	0.412
Re-quantization(24)	0	0
Re-quantization(8)	0.10	0.066
Cropping(20%)	0.09	0.034
Cropping(30%)	0.13	0.083
Average	**0.11**	**0.08**

It is inferred that the proposed WA-GBT method outperforms the existing GBT method with a small reduction in BER. Table 4 displays the average BER comparison of existing and proposed GBT methods.

Table 4 Average BER Obtained by the Proposed Method and Existing GBT Method

Attack	Average	
	GBT	Proposed Method
No attack	0	0
AWGN(20 db)	0	0
AWGN(10 db)	0.0315	0.0210
Re-sampling(6000)	0	0
Re-sampling(4000)	0.0055	0.0015

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LPF (4 kHz)	0	0
HPF (50 Hz)	0.0430	0.0255
AS(0.9)	0.2410	0.2075
AS(0.7)	0.4350	0.3565
Re-quantization(24)	0	0
Re-quantization(8)	0.0875	0.0445
Cropping(20%)	0.0995	0.0630
Cropping(30%)	0.1585	0.0930
Average	**0.074**	**0.052**

There is a reduction in average BER of 0.022. Figures 2 and 3 show the BER comparison chart of proposed method with GBT for various attacks on speech and music respectively. Figure 4 shows the average BER comparison of proposed method and GBT method.

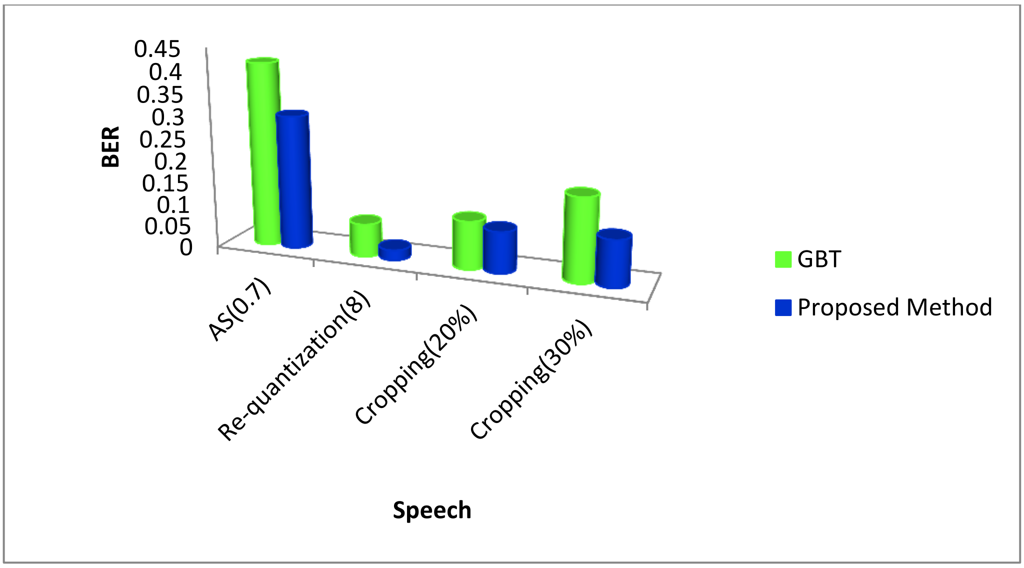

Fig. 2 BER Comparison of GBT and Proposed Method on Speech

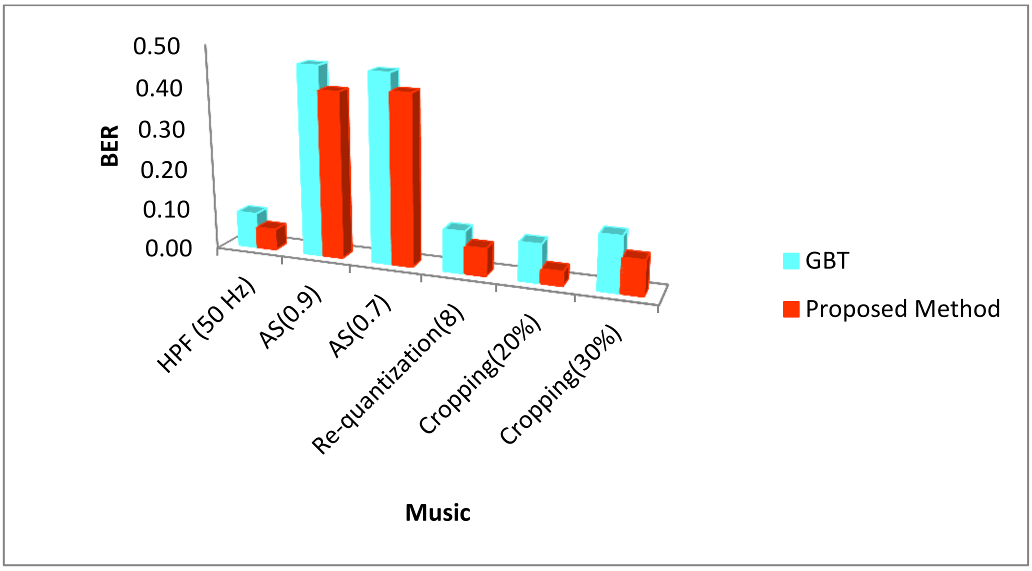

Fig. 3 BER Comparison of GBT and Proposed Method on Music

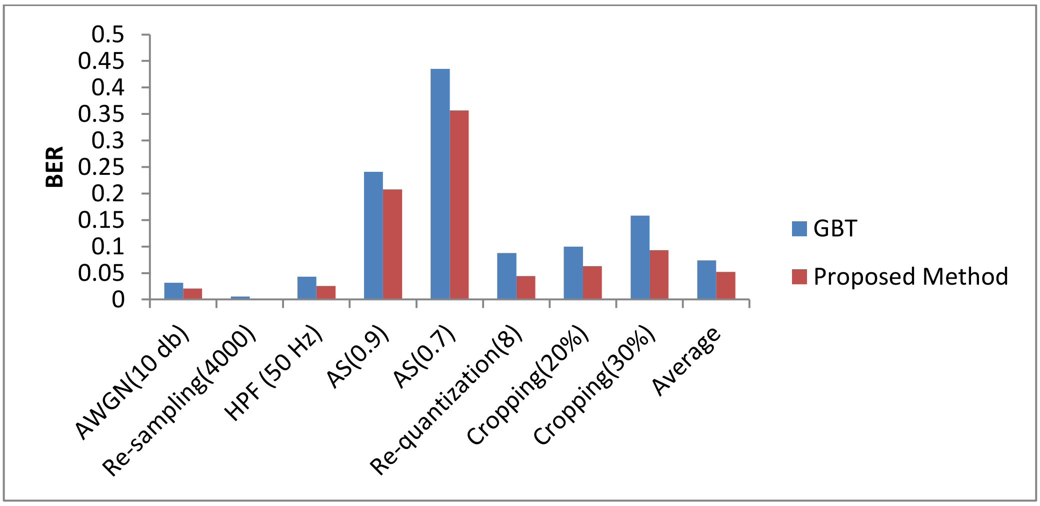

Fig. 4 Average BER Comparison of GBT and Proposed Method

Table 5 compares the proposed method with other transform domains such as DCT, DWT and combination of both. The compared methods are discussed in Section 2.

Table 5 Average BER Comparison with other Related Works

Attack	GBT	DCT-SVD[18]	DWT-SVD[19]	DWT-LU[20]	DWT-DCT[21]	Proposed WA - GBT Method
AWGN-20	0	0	0	0	0	0
Resampling	0	0.03	0		0.09	0
LPF(4 kHz)	0	0	0.189	0.03	0.04	0
HPF (50 Hz)	0.043	0.406	0.358	-	-	0.0255
AS(0.7)	0.435	0.31	-	-	0	0.3565
Re-quantization	0	0	0	0	0	0

In AWGN-20 and re-quantization attack, all the methods have no BER. For other attacks, there is a small reduction of 0.1 in BER obtained by proposed WA – GBT method when compared to other methods. In HPF attack, there is a drastic reduction in BER of GBT and WA-GBT methods. Figure 5 shows the comparison of proposed method with existing methods on various attacks.

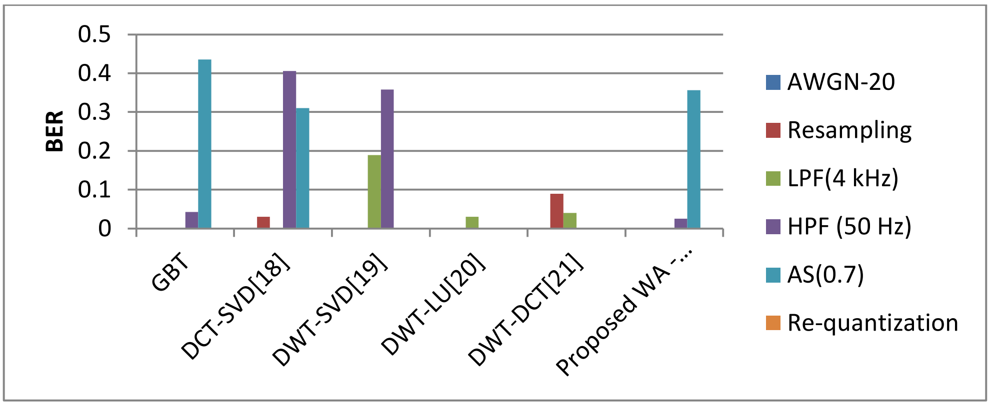

Fig. 5 Bar Chart Comparison of Proposed Method with Existing Methods

V. Conclusion

Audio watermarking plays a vital role in copyright protection, content authentication etc. In this paper, an improved GBT is proposed by adjusting the weights of edges. It is tested on two publicly available datasets. The efficiency of the proposed method is analysed by various attacks with different values. The quality of the audio after embedding the watermark image is measured using PSNR, STOI and BER. The proposed method has a good quality of PSNR with less BER after embedding the watermarks. The extracted watermark is also tested with the original watermark in terms of BER. The proposed method achieves 0.052 BER which is lesser than GBT method.

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