DCT-DWT-Based AudioWatermarking Using SVD

Salma Rizk,Fahmi Khalifa,Mohamed A. Mohamed, Mohy El-Din A. Abou-Soud

Abstrac — This paper proposes anovel and efficient algorithm for digital audio watermarking. The proposed system is ahybrid framework taat utilizes discrete cosine transform (DCT), discrete wavelet transform (DWT) in addition to singular value decomposition (SVD) and quantization. In the proposed method, the original audio is initially segmented into nonoverlapping frames. Watermark data is embedded into the largest singular value of amatrix formed from coefficients of two levels DWT which were obtained from the largest singular value obtained from DCT coefficients of each audio frame by quantization. To evaluate the robustness and imperceptibility of our framework is tested against different types of attacks (e.g, AWGN, resampling, etc) using different types of audio signals,in addition simulation results demonstrate that the proposed watermarking method is not only robust against various attacks but also achieves a good trade-off among imperceptibility, robustness, and payload. In addition, audio quality evaluation tests indicate the high imperceptibility of the watermark in the audio signal. Experimental comparison shows that our method has better performance than of the watermarking scheme reported recently.

Index Terms— DCT, DWT, SVD, Quantization, Imperceptibilty, Robustness, Datapayload.

1 Introduction

In the recent years with the development of internet tech nology it is very easy to access the unauthorized digital or multimedia information. For the protection of multimedia unauthorized information watermark techniques are used, In which embedding any information in a signal is very difficult to remove [1]. Digital watermarking is a technique, which hides digital copyright information into the digital media so that the inserted bits are not recognizable by human senses. It is essential that the embedding mechanism is so robust that can resist common intentional or unintentional attacks. A considerable research focusing on image and video watermarking has been carried out, however, only a few algorithms have been reported on audio watermarking since Human's Auditory System (HAS) is more sensitive than human's visual [7].

There are many requirements (properties) for any digital watermarking especially audio watermarking which are most important for audio watermarking algorithms, *the first is perceptual transparency:* watermarking should be done in a way such that it does not affect the quality of the audio or the hidden data after watermarking. *The second is robustness* : robustness is defined as an ability of the watermark detector to extract the embedded watermark after common signal processing manipulations(attackes).These attacks could be adding noise, adding echo, amplitude modification, resampling, Low pass filtering, Mp3 compression, time stretch, cut samples. *The third* is *watermark bit rate:* the number of bits embedded in a unit of time and is given in bit per second. *The fourth is payload capacity of audio:* the capacity means finding the maximum amount of information that can be safely hidden in an audio. *The fifth is Reliability of the watermark:*there is always a possibility that the user knows the exact algorithm for detecting and extracting the watermark inactive .There are many applications to audio watermarking; Ownership Protection(copyright protection), Proof of ownership, Authentication and tampering detection, Fingerprinting, Broadcast monitoring, Copy control and access control, medical application and Information carrier[4-5].

Generally, audio watermarking techniques can be classified into three groups; time domain techniques, frequency domain techniques and hybrid domain techniques. Time domain techniques such as Least Significant Bit(LSB),Intermediate Significant Bit (ISB) and Empirical Mode Decomposition (EMD)have a higher payload compared to watermarking schemes of other domains as the embedding process performed directly on the original host audio signal, time domain methods are powerless against attacks [7]. Frequency domain techniques such as Fast Fourier Transform *(FFT),* the Discrete Cosine Transform *(DCT),* and the Discrete Wavelets Transform *(DWT)*, employ human perceptual properties and frequency masking characteristics of the Human Auditory Aystem (HAS) for effective watermarking In these techniques, The phase and amplitude of the transform domain coefficients are modified in a certain way to carry the desired watermark information [8]. Hybrid domain techniques such that *(DWT + DCT), (DWT+SVD), (DWT + DCT +SVD).* The three domains have different characteristics, and thus performances of their techniques may vary with respect to the robustness and imperceptibility (inaudibility) requirements of audio watermarking [6].

A significant number of watermarking techniques have been reported in recent years in order to create robust and

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imperceptible audio watermarks. Sakriti Dutt et. al. [1], used the DWT-HAAR transformation which DWT-HAAR produces lesser BER and does not affect the quality of signals. NCC is much better in case of DWT-HAAR, PSNR is higher and MSE is less in case and shows a very good resistance to the attacks. Darabk et. al. [9], adopt acombination of two powerful transforms, DWT, and SVD, which is a numerical technique applied after DWT. This method is maximized the imperceptibility and robustness performance objectives. M. J. Patel et. al.[10] used the watermark as audio signal .and this algorithm is more robust & efficient against some attacks. But also in some attacks DWT & DCT are still gives better results than hybrid method. Khamis et. al. [11], discuss protection of the copyright of audio signal which is belonging to Egyptian Radio and Television Union (ERTU). It is used to protect it through the cloud and allow the Authorized Groups (AuthGs) to get benefit from. It is done using watermarking techniques based on Discrete Cosine Transform (DCT). Shokri et.al. [12], present an audio watermark algorithm with a blind detection which is based on a spread spectrum (SS) technique. A series of simulations were done on the proposed algorithm to estimate the Bit Error Rate (BER) for various values of signal-to-watermarking ratio (SWR) and bit rate. The simulation results show that by decreasing the SWR ratio, the BER ratio is reduced to less than 10^{-3}. Ali.Haj [13], proposes a semi-blind, imperceptible, and robust digital audio watermarking algorithm and is based on cascading two well-known transforms: dwt & svd transform. Imperceptibility, robustness, and high data payload of the proposed algorithm are demonstrated using different musical clips. Rahman et.al.[14], describe the techniques developed till date for audio watermarking and audio feature extraction techniques in brief. Singh et.al. [15], incorporate the detail study watermarking definition, concept and the main contributions in this field such as categories of watermarking process that tell which watermarking method should be used. Vijayakumare et.al. [16], discuss various types of watermarking used to secure the data. K.Sathees et.al [17], present a brand new accommodative audio watermarking formula supported Empirical Mode Decomposition (EMD) is introduced. The audio signal is split into frames and everyone is decomposed adaptively, by EMD, into intrinsic periodic elements known as Intrinsic Mode Functions (IMFs). The watermark and therefore the synchronization codes are embedded into the extrema of the last IMF, an occasional frequency mode stable beneath different attacks and protective audio sensory activity quality of the host signal. All this mean that, our methodology is applied to any image and any audio signals. .Experimentation has ensured the mark physical property, the ability of detection of the mark and therefore the hardiness against completely different varieties of attacks. Rahman et al,[18] present a new adaptive audio watermarking algorithm based on Empirical Mode Decomposition (EMD) is introduced. Satheesh *et al*, [20] presenta digital audio watermarking scheme based on spread spectrum technique to embed the watermark.

In this paper, we introduce anovel audio watermarking method.The proposed framework adopts acombination of three powerful transforms, namely discrete cosine transform (DCT), discrete wavelet transform (DWT) in addition to singular value decomposition (SVD) where the DCT has energy compression properties that improve the transparency of the watermark, DWT, which is a capable of giving a time-frequency representation of any given signal, and SVD, which is a numerical technique applied twice after DWT and DCT to give us more robustness.We start with DCT as DCT quantizes the data,and the original data is lost, and we can therefore protect data from attacks. And then DWT which shows better robustness and inaudibility, and finally applied SVD in which a high value of S (1, 1) doesn't affect the watermark bits.

2 Proposed Audio Watermarking Method

In this section is afully described the proposed DCT-DWT-SVD algorithm. The algorithm consists of two processes: watermark embedding and watermark extraction processes. Details of the main steps of the proposed framework are given below.

2.1 Watermark Embbeding Process

The proposed watermark embedding process is shown in Fig.1. The embedding process is described as follows:

Step (1): The binary watermark image is resized into square matrix (N x N) depending on frame size and then converted into one dimensional watermark sequence W = w (n), 1 < n < L , and L=NxN.

Step (2): The original audio signal X is then segmented into nonoverlapping frames F= {F1, F2… FL}.

Step (3): The DCT is applied to each frame F_i to obtain the vector Y_i. Each Y_i is converted into square matrix DZ_i.

Step (4): SVD is performed to decompose each matrix DZ_i into three matrices: U_i, S_i, and V_i. The SVD operation is represented as follows: $DZ_i = U_i \times S_i \times V_i^T$.

Step (5): Store the diagonal coefficients of S_i into a vector Sn_i.

Step (6): applying 2 level DWT to Sn_i. This operation produces three sets of coefficients D1, D2, and A2, where D1, D2 and A2 represent the detailed and approximate coefficients, respectively. The detailed coefficients D1 and D2 of each frame are arranged into a one dimensional Matrix H_i which is shown in Fig.2, where i indicates the frame number.

Step (7): SVD is performed to decompose each matrix Hi into three matrices: $U1_i$, $S1_i$, and $V1_i$.

Step (8): In order to guarantee the robustness and transparency in the proposed method, a watermark bit is embedded into the highest singular value $S1_i$ (1, 1) of each matrix $S1_i$ by using a quantization function. Q is a predefined quantization coefficient. A small value of Q will lead to goodImperceptibility of the watermarking method but will provide low robustness to attacks, whereas a large value of Q will lead to good robustness to attacks but will provide low imperceptibility of the watermarking method. Thus, an optimal value of Q should be selected. If the bit to be embedded is a '1', we increase the value of $S1_i$ (1,1). And, if the bit to be embedded is a '0', we decrease the value of $S1_i$ (1,1). This embedding method can be formulated by the following quantization function (1):

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$$S1n(1,1) = \begin{cases} S1(1,1) + \frac{Q}{C}, & if\ \mathrm{w(m)=1} \\ S1(1,1) - \frac{Q}{C}, & if\ \mathrm{w(m)=0} \end{cases} \qquad (1)$$

Where C is user-defined constant.

Step (9): Inverse SVD is applied to obtain the modified matrix DZn_i which is given by DZn=U1*S1n*V1 which contains the modified detailed coefficients D1n, D2n.

Step (10): After substituting the coefficients Dn1 and Dn2 for D1 and D2, respectively, a two-level inverse DWT is performed to obtain the one dimensional matrix DDnew.

Step (11): obtain Snnew from DDnew and perform inverse SVD Dzznew=U*Snnew*V' to obtain square matrix Dzz. And then converted to a vector and applying inverse DCT to obtain the watermarked audio frame.

Step (12): finally, all watermarked frames are concatenated to calculate the watermarked audio signal.

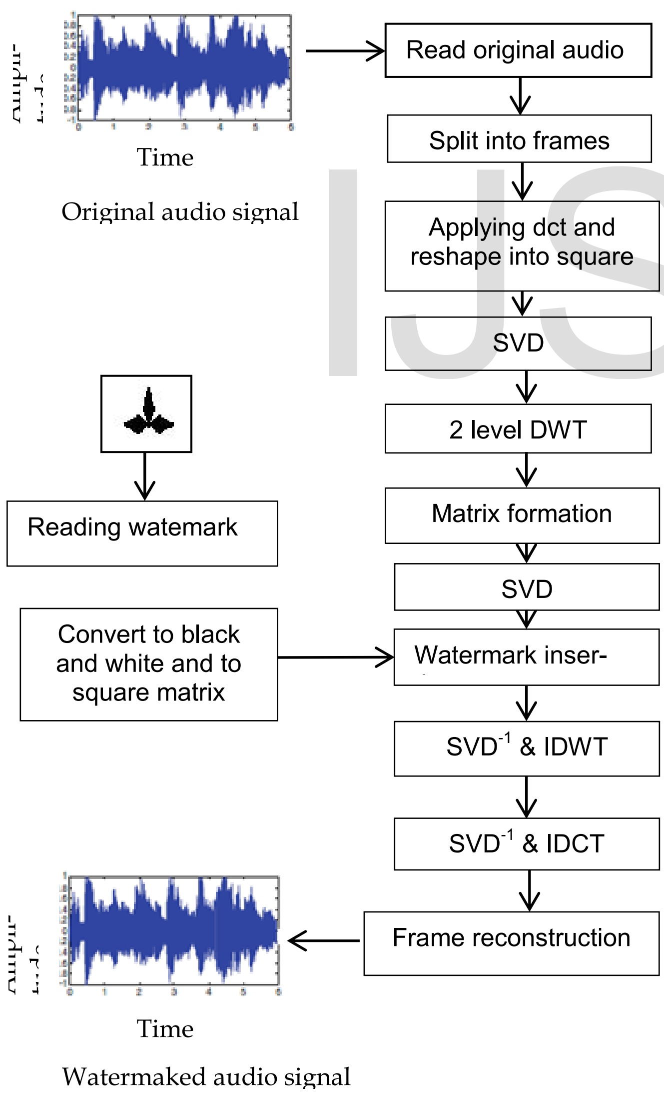

Fig1 watermark embedding process

2.2 Watermark Extracting Process

The proposed watermark extracting process is shown in Fig.3 and the main steps of the extracting process is described as follows:

Step (1): DCT is performed on each frame F_i of the attacked watermarked audio signal *X* and convert each vector into square matrix (DwZ).

Step (2): SVD is performed on each matrix DwZ to obtain Uw_i, Sw_i, and Vw_i.

Step (3): Store the diagonal coefficients of Sw_i into a vector Swn_i. Applying 2 level DWT to Swn. This operation produces three sets of coefficients Dw1, Dw2, and Aw2, where Dw1, Dw2 and Aw2 represent the detailed and approximate coefficients, respectively. The detailed coefficients Dw1 and Dw2 of each frame are arranged into a one dimensional Matrix Hw_i.

Step (4): SVD is performed on Hw to obtain Uw1, Sw1, Vw1.

Step (5): The largest singular value of each diagonal matrix Sw1 (1, 1) located at the same position in the pre-embedding process is calculated.

Step (6): The watermark sequence is extracted as follows in (2):

$$w_s(m) = \begin{cases} 1, & if sw1(1,1) > s1(1,1) \\ 0, & otherwise \end{cases} \qquad (2)$$

Step (7): Finally, the binary watermark image is obtained byrearranging the watermark sequence into a square matrix of size *M xM*.

H =

D1	*D2*	*D2*

Fig.2 Matrix formation (Hi) of the detailed coefficients D1 and D2 for each frame

3 Experimental Results and Discussion

In this study, 16-bit mono audio signal in wave format sampled at 44.1 kHz were used. Each audio file contains 262,144 samples (duration 7.8622s). By using a frame size of 256 samples, we have 1,024 nonoverlapping frames for each audio signal. In each frame of the audio signal, we embed 1-bit binary watermark information. The embedded watermark is a binary logo image of size M *x* M = 32 *x 32* = 1024 bits, as the selected value for the quantization coefficient Q is 0.25. For convenience, the selected value for constant C is 10. These parameters were selected in order to achieve a good trade-off among the conflicting requirements of imperceptibility, robustness, and data payload.

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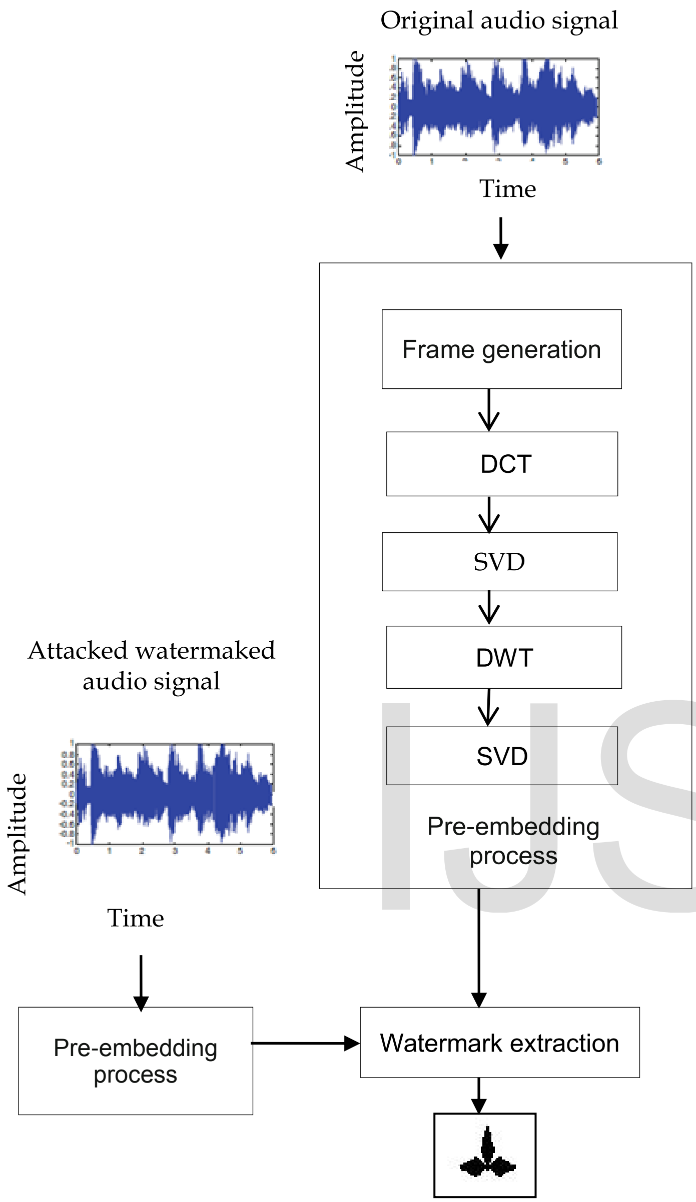

Fig3 watermark extracting process

3.1 Imperceptibility Results

Imperceptibility ensures that the quality of the signal is not perceivably distorted and the watermark is imperceptible to listeners. To measure imperceptibility, different authors use different metrics; however, the most commonly used metrics are signal-to-noise ratio (SNR) and listening tests [13]. *The Signal-to-noise ratio* (SNR) is a statistical difference metric which is used to measure the similitude between the undistorted original audio signal and the distorted watermarked audio signal. The SNR computation is done according to eq (3), where a corresponds to the original signal, and An′ corresponds to the watermarked signal [9].

$$SNR = 10 \log \frac{\sum_n A_n^2}{\sum_n (A_n - A'_n)^2} \qquad (3)$$

Based on our experiments we obtained the dB values of SNR given in Table 1. As demonstrated in the table, the values of the proposed algorithm are much higher than the compared method in [22], and Fig 4 shows the imperciptiblity of watermarked audio signal using our proposed method.

Table1

Imperceptibilty (SNR, MSE, CORR) **V**alues

Method	SNR	MSE	Corr_coef
DWT-DCT-SVD[22]	46.8949	0.0026	0.9361
Proposed(DCT-SVD-DWT-SVD)	58.1976	3.11e04	0.9945

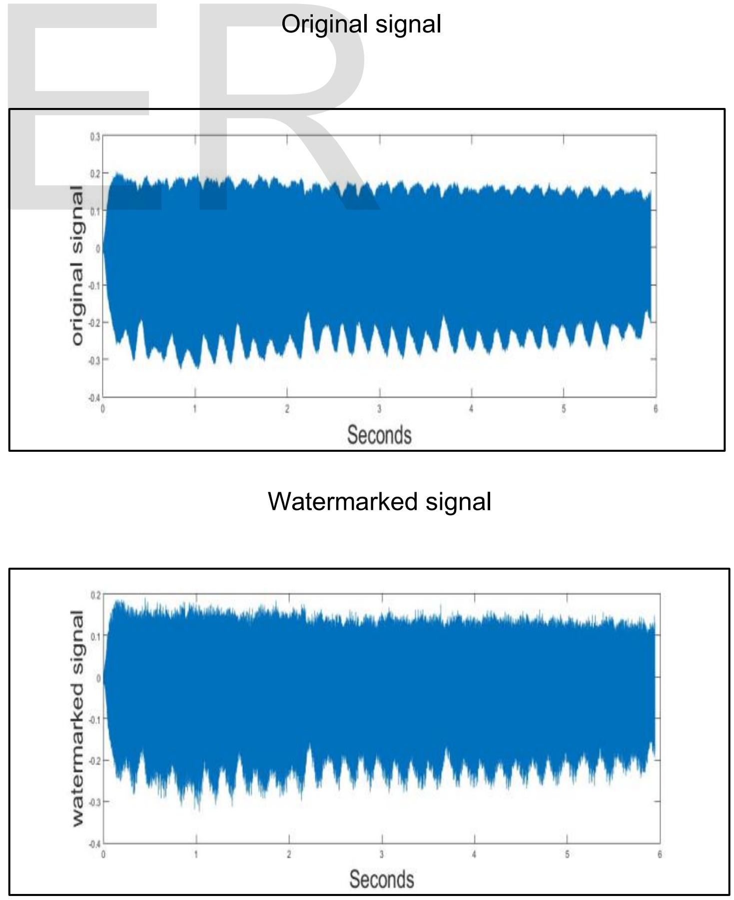

Fig 4 imperciptiblity of watermarked audio signal using our proposed method

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3.2 Robustness Test

In order to test the robustness of the proposed method, we used the normalized correlation (NC). The NC is used to evaluate the correlation between the original watermark and the extracted watermark and is given by (4):

$$NC = \frac{\sum_{i=1}^{p}\sum_{j=1}^{q} w(i,j)*w\prime(i,j)}{\sqrt{\sum_{i=1}^{p}\sum_{j=1}^{q} w^2(i,j)}\sqrt{\sum_{i=1}^{p}\sum_{j=1}^{q} w\prime^2(i,j)}} \qquad (4)$$

The correlation factor has a range of (0 - 1) in which 0 and 1 represent random and perfect linear relationships, respectively.In addition to NC, the Bit Correction Ratio (BCR) is also used to test the robustness of the proposed method. BCR expresses the difference between the watermark bits embedded in the host audio signal, and the watermark bits extracted at the receiver side [7]. The BCR is calculated by eq (5):

$$BCR = \frac{E}{P*Q} * 100\ \% \qquad (5)$$

Where *E* is the number of corrected bits of the watermark during the extraction process and (P * Q) is the size of watermark image. Our experiment yielded the NC and BCR values shown in Table 2. As shown in the table, the values of the proposed algorithm are much higher than the compared method in [22]

Table2
Robustness (NC, BCR) Values:

Method	NC	BCR
DWT-DCT-SVD	0.9570	98
Proposed(DCT-SVD-DWT-SVD)	1	100

In addition to imperciptibilty test we also evaluate the performance of our approach against different types of attacks namely; (AWGN, Cropping, Resampling and Requantization)

1. Additive white Gaussian noise (AWGN): AWGN is added to the watermarked audio signal.
2. Cropping: 10,000 samples are removed from the front, middle, and end parts of the watermarked audio signal and then these samples are replaced by the watermarked samples attacked with AWGN.
3. Resampling: The watermarked signal originally sampled at 44.1 kHz is resampled at 22.050 kHz and then restored by sampling again at 44.1 kHz.
4. Requantization: The 16-bit watermarked audio signal is quantized down to 8 bits/sample and requantized up to 32 bits/sample.

Table 3 shows the extracted watermarks along with the NC and BER values after several different attacks for the audio signal ‘flute’. The minimum NC value and the maximum BER value are 0.9581and 1.9531, respectively. The extracted watermark images are visually similar to the original watermark image. This clearly documents high performance of the proposed method against different attacks.

3.3 Data Payload

Data payload refers to the number of bits (watermark) which embeds in a unit of time. For audio, data payload refers to the number of embedded bits per second that are transmitted. Different applications require different data payload. For ex, copy control applications require a few bits embedded in cover works [21]. Data Payload is measured as the number of bits embedded within one second of the audio signal (bps). The payload is computed by multiplying number of frames per second by the bit capacity of the frame. The number of frames per second depends on the frame length and is computed by dividing the 44.1 KHz sampling rate by the frame length. The payload increases as the frame length decreases. However, short-length frames degrade performance and result in unacceptable imperceptibility and robustness results [13].The data payload for any watermarking method should be more than 20 bps [22]. The data payload of the proposed method is 132bps, and this result is same as datapayload of the compared method [22].

4 Conclusion

We propose a new method for audio watermarking.The proposed method had shown a good imperceptible watermarked audio and high ro-bustness against different attacks (e.g. AWGN, cropping, resampling and re-quantization. This is because the watermark is embedded into the largest singular value of the DWT sub-bands obtained from singular values of the DCT coefficients of each audio frame, and minor differences of the largest singular values do not affect the quality of the audio signal. The proposed method performs better than audio watermarking methods in terms of vulnerability (imperceptibility), robustness (durability), and data payload.This has been experimentally validated using different types of audio signals.

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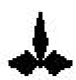
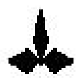
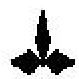
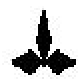
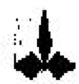
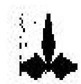
Table 3
Extracted watermark image with NC and BER for original singal

Attack	No attack	AWGN (55db)	Resampling (22050 Hz)	Quantized (8bit)	Quantized (32bit)	Cropping (front)	Cropping (middle)	Cropping (end)
NC	1	0.9581	1	1	1	0.9725	0.9935	0.9683
BER	0	1.9531	0	0	0	1.2695	0.2930	1.4648
Ectracted watermark								

Tables (4, 5, 6) illusturate NC and BER ofthe extracted watermarks for Different audio signals.

Table 4
PERFORMANCE METRICS OF FIRST AUDIO SIGNAL
(Classic-- mono channel, (16bit) per sample, 44100, sampling rate, duration (30s))

	SNR	MSE	COR1	BER	COR2
No attack	58.1976	0.00031	0.9945	0	1
AWGN (55db)				1.9531	0.9581
Resample (22050)				0	1
Requantize (8bit)				0	1
Cropping (front)				1.4648	0.9683
Cropping (middle)				0.2930	0.9935
Cropping (end)				1.2695	0.9725

Table 5
PERFORMANCE METRICS OF SEC
(Folk --mono channel, (16bit) per sample, 44100

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	SNR	MSE	COR1	BER	COR2
No attack	67.9615	0.00056	0.9993	0	1
AWGN(55db)				1.5625	.9663
Resample (22050)				0	1
Requantize (8bit)				0	1
Cropping (front)				1.3672	0.9704
Cropping (middle)				0.1953	0.9957
Cropping (end)				1.2695	0.9725

Table 6

PERFORMANCE METRICS OF THIRD AUDIO SIGNAL

(Jazz-- mono channel, (16bit) per sample, 44100, Sampling rate, duration (7.8622s))

	SNR	MSE	COR1	BER	COR2
No attack	42.3605	0.0024	0.9383	1.3672	0.9704
AWGN (50db)				1.5625	0.9663
Resample (22050)				1.3672	0.9704
Requantize (8bit)				1.2695	0.9725
Cropping (front)				2.1484	0.9541
Cropping(middle)				1.3672	0.9704
Cropping (end)				3.3203	0.9304

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