ISSN 2229-5518

Improved Audio Watermarking Using DWT-SVD

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Abstract— Digital audio watermarking involves the concealment of data within a discrete audio file. Applications for this technology are numerous. Intellectual property protection is currently the main driving force behind research in this area. In this paper we present an efficient audio watermarking algorithm in the frequency domain by embedding an inaudible audio water mark. Comparison of two different algorithms i.e. Discrete Cosine Transform (DCT)-Singular Value Decomposition (SVD) and Discrete Wavelet Transform (DWT)-SVD is presented here. The effectiveness of these algorithms is verified by conducting experimentation. Experimental results show that the watermarked audio has good imperceptibility and is robust against different kinds of attacks, such as noise adding, re-sampling, cropping.

Index Terms— Audio Watermarking, Attacks, DCT, DCT-SVD, DWT, DWT-SVD, MOS evalauation, Singular Value Decomposition.

1 INTRODUCTION

THE rapid development of the Internet and the digital information revolution cased significant changes in the global society, ranging from the influence on the world economy to the way people nowadays communicate [1]. Digitizing of multimedia data has enabled reliable, faster and efficient storage, transfer and processing of digital data. It also leads to the consequence of illegal production and redistribution of digital media. Digital watermarking is identified as a partial solution to related problems which allow content creator to embed hidden data such as author or copyright information into the multimedia data [2]. In cryptographic techniques significant information is encrypted so that only the key holder has access to that information. Once the information is decrypted the security is lost. Information hiding is unlike cryptography, message is embedded into digital media, which can be distributed and used normally. Information hiding doesn't limit the use of digital data. Within past few years several algorithms for embedding and extraction of watermark in audio sequence have been published [3-7]. Almost all audio watermarking algorithms work by exploiting the perceptual property of Human Auditory System (HAS). The simplest visualization of the requirements of information hiding in digital audio is possible via a magic triangle [8]. Inaudibility, robustness to attacks and the watermark data rate are in the corners of the magic triangle. In order to satisfy the requirements of magic triangle, watermarks are seen embedded in Fourier domain [3], time domain [4], sub-band domain [6], wavelet domain [7] and by echo hiding [5].

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2 DCT, DWT & SVD TECHNIQUES

The DCT and DWT transforms have been extensively used in many digital signal processing applications. SVD is a useful tool of linear algebra with several applications in image compression, watermarking and other areas of signal processing. A few years ago, SVD is explored for image watermarking applications [9, 10]. The brief introduction of these three techniques are presented in this section .

The DCT transform: The discrete Cosine Transform is a technique for converting a signal into elementary frequency components [11]. The most common DCT definition of a 1-D sequence of length N is

$$C(u)=\alpha(u)\sum_{x=0}^{N-1} f(x)\cos\left[\frac{\pi(2x+1)u}{2N}\right], \quad (1)$$

For u=0,1,2,…,N-1. Similarly, the inverse transformation is defined as

$$f(x)=\sum_{u=0}^{N-1}\alpha(u)C(u)\cos\left[\frac{\pi(2x+1)u}{2N}\right], \quad (2)$$

for x=0,1,2,….N-1. In both equations (1) and (2) $\alpha(u)$ is defined as

$$\alpha(u)=\begin{cases}\sqrt{\frac{1}{N}} & for \;\; u=0\\ \sqrt{\frac{2}{N}} & for \;\; u\neq 0\end{cases} \quad (3)$$

It is clear from (1) that for u=0, C(u=0)= $\sqrt{\frac{1}{N}\sum_{x=0}^{N-1} f(x)}$.

Thus the first transform coefficient is the average value of the sample sequence. In literature, this value is referred to as the DC Coefficient. All other transform coefficients are called the AC Coefficients [12].

In particular, a DCT is a Fourier-related transform similar to the Discrete Fourier Transform (DFT), but using only real numbers. DCTs are equivalent to DFTs of roughly twice the length, operating on real data with even symmetry (since the Fourier transform of a real and even function is real and even), where in some variants the input and/or output data are shifted by half a sample.

The DWT Transform: The discrete wavelet transform has received a tremendous amount of interest in many important signal processing applications including audio and image watermarking [13, 14 and 15]. With the DWT, the audio signal can be transformed into frequency domain ranging from low frequency to high frequency. Besides, the high frequency spectrum is less sensitive to human ear. That is the reason why the high frequency component is usually discarded in the compression process. Therefore, information to be hidden can be embedded into the low frequency component to against the compression attack.

The DWT is defined by the following equation

$$W(j,k)=\sum_j\sum_k x(k)2^{-j/2}\Psi(2^{-j}n-k)$$

Where $\Psi(t)$ is a time function with finite energy and fast decay called the mother wavelet. The DWT analysis can be performed using a fast, pyramidal algorithm related to multirate filterbanks [16].

As a multirate filterbank the DWT can be viewed as a constant Q filterbank with octave spacing between the centers of the neighboring higher frequency subband. In the Pyramidal algorithm the signal is analyzed at different frequency bands with different resolution by decomposing the signal into a coarse approximation and detail information. The coarse approximation is then further decomposed using the same wavelet decomposition step. This is achieved by successive highpass and lowpass filtering of the time domain signal and is defined by the following equations:

$$y_{high}[k]=\sum_n x[n]g[2k-n]$$

$$y_{low}[k]=\sum_n x[n]h[2k-n]$$

Where $y_{high}[k]$, $y_{low}[k]$ are the outputs of the highpass (g) and lowpass (h) filters, respectively after subsampling by 2.

The SVD Transform: A few years ago, a third transform called the Singular Value Decomposition (SVD) was explored for watermarking [17]. The SVD for square matices was discovered independently by Beltrami in 1873 and Jordan in 1874, and extended to rectangular matrices by Eckart and Young in the 1930s. It was not used as a computational tool until the 1960s because of the need for sophisticated numerical techniques. In later years, Gene Golub demonstrated its usefulness and feasibility as a tool in a variety of applications [18]. SVD is one of the most useful tools of linear algebra with several applications in image compression and other signal processing fields.

3 DCT-SVD ALGORITHM

Watermark embedding procedure

Algorithm for embedding an audio in original audio using DCT-SVD:

Step 1: Sample the original audio signal at a sampling rate of particular number of samples per second. Then, partition the sampled file into frames each having certain samples.

Step 2: Performing DCT transformation on original audio signal. This operation produces a Two sub-bands: A, D. The D represents the Details sub-band, and A represents the approximation sub-band.

Step 3: Apply SVD to the DCT performed approximation sub-band A. SVD decomposes the DCT coefficients into three matrices namely, U, S, V^T. Where U is Unary matrix, S is Singular matrix.

Step 4: Perform the steps 2 and 3 to the watermark signal also.

Step 5: Embed the watermark audio bits into the DCT-SVD-transformed original audio Signal according to the formula $S_{em} = S + k * S_w$ . . . . . .(3)

Where S = singular matrix of original audio signal
S_w = singular matrix of watermark audio signal
S_{em} = singular matrix of watermarked audio signal

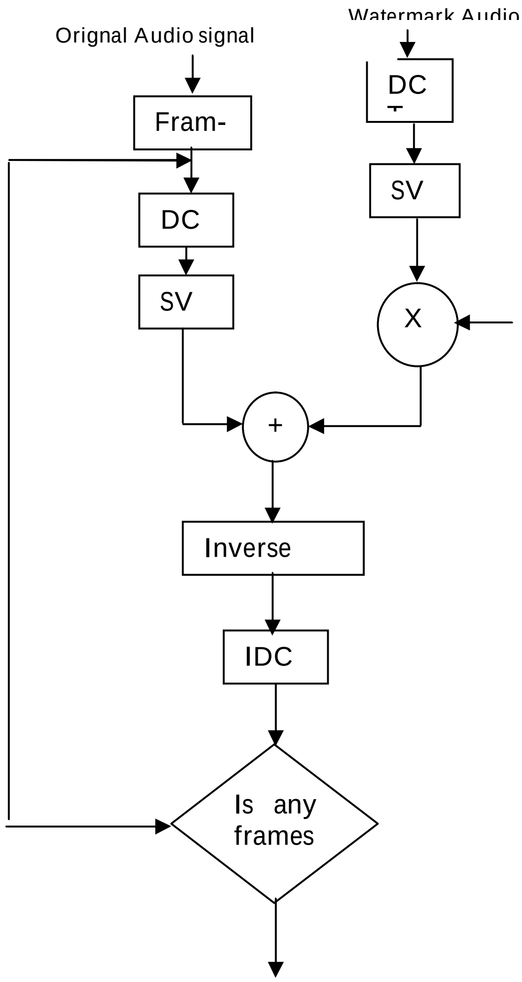
Step 6: Produce the final watermarked audio signal as follows:

→ Apply the inverse SVD operation using the *U* and V^T matrices, which were unchanged, and the *S* matrix, which has been modified according to Equation (3).

→ Apply the inverse DCT operation to obtain each watermarked audio frame. The overall watermarked au-

ISSN 2229-5518

dio signal is obtained by summing all Watermarked frames.



Algorithm for extracting an audio in original audio using DCT-SVD:

Step 1: Perform steps 2 and 3 of the embedding procedure until the *S* matrix is obtained for all frames of the watermarked audio signal.

Step 2: Compose the singular matrix of watermark audio signal in the DCT-SVD transformed watermarked audio signal according to the formula

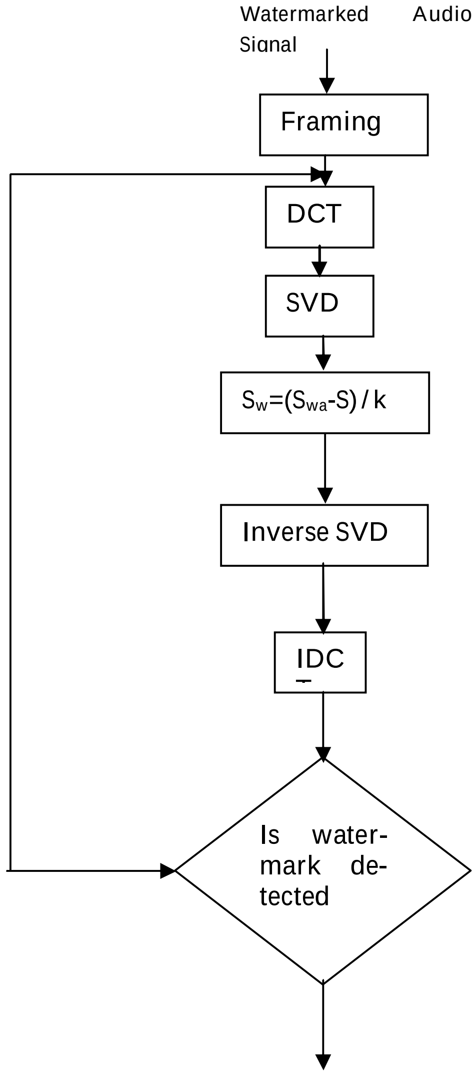
$S_{ex}= (S_{em}-S)/0.01$ ……….(4)

Where S_{ex} = singular matrix of extracted watermark audio signal.

Step 3: Produce the final watermark audio signal as follows:

→ Apply the inverse SVD operation using the *U* and V^T matrices, which were unchanged, and the *S* matrix, which has been modified according to Equation (4).

→ Apply the inverse DCT operation to obtain each watermarked audio frame.



4 DWT-SVD ALGORITHM

Algorithm for embedding an audio in other audio:

Step 1: Sample the original audio signal at a sampling rate of particular number of samples per second. Then, partition the sampled file into frames each having certain samples.

Step 2: Performing DWT transformation on original audio signal..This operation produces Two sub-bands: A, D.The D represents Details sub-band, and A represents the Approximation sub-band.

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Step 3: Apply SVD to the DWT performed approximation sub-band A. SVD Decomposes the DWT coefficients into three matrices namely, U, S, V^T. Where U is Unary matrix, S is Singular matrix.

Step 4: Perform the steps 2 and 3 to the watermark signal also.

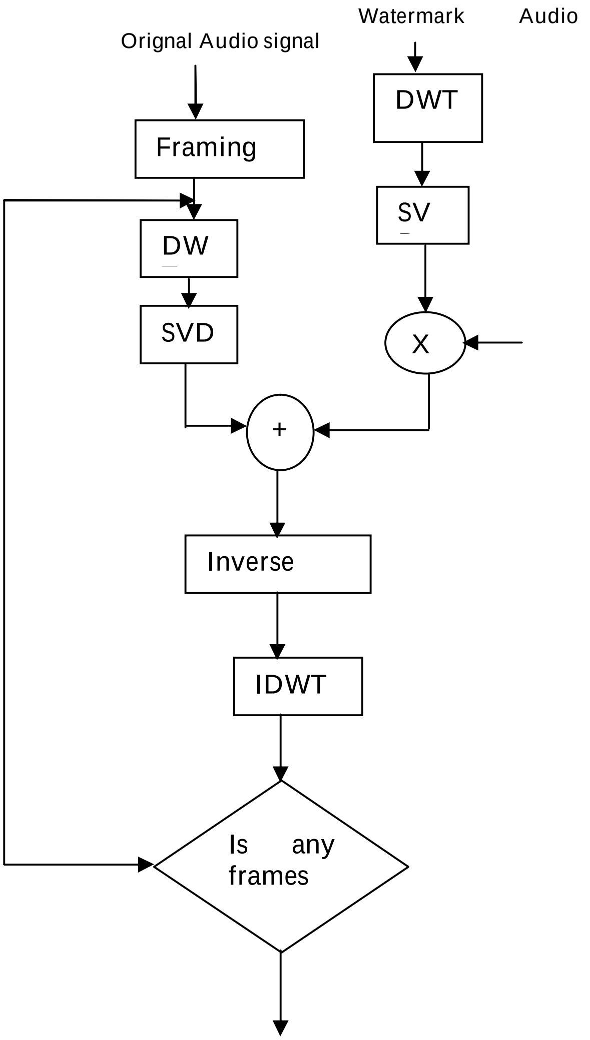
Step 5: Embed the watermark audio bits into the DWT-SVD-transformed original audio signal according to the formula $S_{em} = S + k * S_w$ . . . . . .(3)

Where S = singular matrix of original audio signal
S_w = singular matrix of watermark audio signal
S_{em} = singular matrix of watermarked audio signal

Step 6: Produce the final watermarked audio signal as follows:

→ Apply the inverse SVD operation using the *U* and V^T matrices, which were unchanged, and the *S* matrix, which has been modified according to Equation (3).

→ Apply the inverse DWT operation to obtain each watermarked audio frame. The overall watermarked audio signal is obtained by summing all Watermarked frames.



Algorithm for extracting an audio in other audio using DWT-SVD:

Step 1: Perform steps 2 and 3 of the embedding procedure until the *S* matrix is obtained for all frames of the watermarked audio signal.

Step 2: Compose the singular matrix of watermark audio signal in the DWT-SVD transformed watermarked audio signal according to the formula

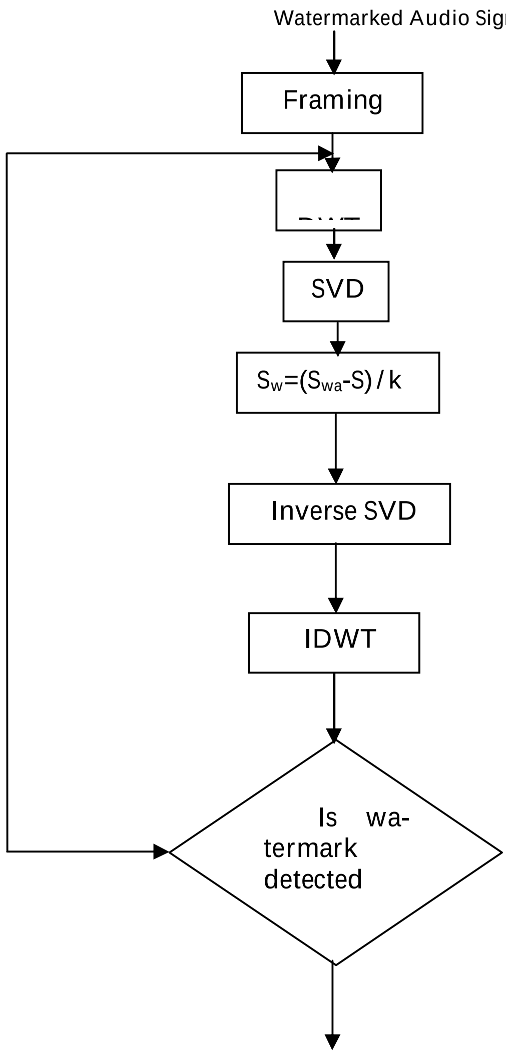
$S_{ex} = (S_{em} - S)/0.01$ . . . .(4)

Where S_{ex} = singular matrix of extracted watermark audio signal.

Step 3: Produce the final watermark audio signal as follows:

→ Apply the inverse SVD operation using the *U* and V^T matrices, which were unchanged, and the *S* matrix, which has been modified according to Equation (4).

→ Apply the inverse DWT operation to obtain each watermarked audio frame.



5 EXPERIMENTAL RESULTS

Four classes of audio signals like speech, pop music, rock music and instrumental were used to study the performance of the DCT-SVD and DWT-SVD algorithms. These classes were chosen because each class has different spectral properties.

Imperceptibility Test: Imperceptibility is related to the perceptual quality of the embedded watermark audio within the original audio signal. To measure imperceptibility, we use Signal-to-Noise Ration (SNR) as an objective measure, and a listening test as a subjective measure.

For subjective quality evaluation, a listening test was performed with five listeners to estimate the Mean Opinion Score (MOS) grade of the watermarked signals for four different signals. Each listener was presented with the pairs of original signal and the watermarked signal and asked to report whether any difference could be detected between the two signals. The five people listed to each pair for 15 times, and they gave a grade for the pair. The average grade for each pair from all listeners corresponds to the final grade for the pair. MOS evaluation criterion and MOS for the two techniques are listed in the Tables1 and 2 respectively.

Table 1. MOS evaluation criterion

Score	Watermark imperceptibility
5	Imperceptibility
4	Perceptibility but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Table 2. MOS for the two techniques

Audio Signal	DCT-SVD	DWT-SVD
SPEECH	4.95	5
POP MUSIC	4.81	4.93
ROCK MUSIC	4.76	4.95
INSTRUMENT	4.54	4.9

SNR in db is calculated using the following equation [2].

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

Where, N is the length of audio signal
x(n) is the original signal
$x^l(n)$ is the watermarked signal
n=0,1,2,3,……N

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.

Table 3. PSNR Evaluation

Class of Audio Signal	Attack Type	DCT-SVD	DWT-SVD
SPEECH	Without Attack	56.3394	61.9459
	Resample	54.1057	47.7226
	Noise	19.5943	19.8746
	Gaussian Noise	29.2365	31.5413
	Cropping	41.6865	59.6636
POP MUSIC	Without Attack	42.9722	52.9715
	Resample	18.806	26.5770
	Noise	6.191	4.664
	Gaussian Noise	14.8786	16.2860
	Cropping	38.6206	39.2680
ROCK MUSIC	Without Attack	48-1049	50.6182
	Resample	20.9047	52.1388
	Noise	4.0980	2.1915
	Gaussian Noise	14.2720	18.1219
	Cropping	15.6720	21.6730
INSTRU-STRU-MENT	Without Attack	54.4549	69.5287
	Resample	29.3643	31.3434
	Noise	12.3940	11.7206
	Gaussian Noise	20.2885	23.7522
	Cropping	37.5636	42.2612

6 CONCLUSION

An efficient audio watermarking algorithm in the frequency domain by embedding the inaudible audio water mark is presented here. It is verified that the DWT-SVD technique is robust for most of the attacks rather than the DCT-SVD. By means of combining the two transforms DWT-DCT along with SVD, inaudibility and different levels of robustness can also be achieved.

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