

# Transformed Domain Audio Watermarking Using DWT and DCT

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## Abstract

The main object of all types of watermarking algorithm is to improve performance parameters like Robustness, Imperceptibility, capacity, data rates etc. This is also observed that the performance parameters of Transformed domain are better as compared to time domain. A lot of Transformation techniques are available for the analysis of any signal or for the transformation of any signal from one domain to an another domain to extract the desired information for example FFT, STFT, DCT, DWT etc. each transformation technique has their own set of advantages and disadvantages and their suitability for an specific applications In this paper we are going to propose an unique method of audio watermarking which will take the advantages of both energy compressing property of D.C.T. and multi resolution property of D.W.T. and embedded our watermark with audio signal such that it maintain a good perceptual Quality (S.N.R).as well as shows high degree of robustness (N.C.) against various signal processing attacks like compression, Re sampling, Re quantization, filtering cropping etc.

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## Keywords

Audio Watermarking, DWT, DCT.

## Introduction and Motivation

Digital audio watermarking is a technique for embedding additional data along with audio signal. Embedded data is used for copyright owner identification [2]. Audio watermarking is basically a technique to embedding some information (for example picture or some text) with an audio signal in such a way that it will not effect the perceptual quality of an audio signal and robust against various signal processing attacks and can be produce as a proof of ownership (copyright information) or verify the authenticity of audio contents. The main driving force behind the audio watermarking is to stop the unauthorized copying and distribution of audio files or digital media. now a day we are living in the age of technology and internet become a great market place where each person is connected with an another one. Again care must be taken in to account when we are transferring or uploading our audio file over internet because there is a chance that someone has copying your audio contents and release the pirated version of your original audio file . So watermarking is a technique all about that how to stop such kind of piracy with digital media over internet.

## Applications

Copyright protection is the main application of watermarking ,watermark can be produce as a proof of ownership in case of any disputes, contents authentication is an another application of watermarking the authenticity of any digital media can be checked with the help of watermark information, temper detection ,finger printing, copy and access control are some main application of watermarking further watermarking can be used in medical applications such as the medical report of any patent can be watermarked to avoid any possibility of report exchange further at air traffic monitoring a watermarking can be used to avoid any miscommunication.

## Requirement of an Efficient Watermarking

1. **Imperceptibility:** by imperceptibility simply means that the perceptual quality of original signal should not be affected due to watermark embedding.

2. **Robustness:** watermark should be robust against various type of signal processing attacks such as compression, re sampling, re quantization, cropping etc.
3. **Capacity:** by capacity we simply means how much amount of watermark information can be added to the original audio signal without effecting its quality.
4. **Security:** watermark should be enough secure that only original embedder can detect the watermark no one else should be able to detect it.
5. **Speed:** speed refers to the time in embedding or extracting watermark information.

However there is a trade off between the various requirement of watermarking if we improve the robustness then definitely imperceptibility and capacity will be effected. And if we want to improve the perceptual quality then we have to do compromise with robustness one has to do some compromise according to some specific applications.

## Various Attacks on Watermark

A watermark may go through various common signal processing attacks hence it should robust against the following attacks.

**Re-sampling:** A watermark should be robust against re sampling attack a watermarked signal may be re sampled many times at different sampling rate intentionally or unintentionally.

**Re-quantization:** during A/D and D/A conversion a watermarked signal can be re quantized with different quantization levels so our watermark should be robust again re quantization attack.

**Compression:** An audio file may be compressed during the transmission and distribution the embedded watermark signal should be robust against compression.

**Filtering:** the various frequency components of watermarked signal can be filtered or we can say any specific frequency component of watermarked signal can be attenuated the watermark should not be effected by filtering.

**Cropping:** cropping means to crop the certain part of watermarked signal and replace it with an another signal.

**Adding noise** is against a very common signal processing attack AWGN noise may be introduced in watermarked signal.

## Main Algorithms and Domain of Audio Watermarking

Most audio watermarking schemes rely on the imperfections of the human auditory system (HAS). In particular, HAS is insensitive to small amplitude changes in the time and frequency domains, allowing the addition of weak noise signals (watermarks) to the host audio signal such that the changes are inaudible. In the time domain, it has been demonstrated that the HAS is insensitive to small level changes and insertion of low-amplitude echoes. Data hiding in the frequency domain takes advantage of the insensitivity of the HAS to small spectral magnitude changes [1].

Further, HAS is insensitive to a constant relative phase shift in a stationary audio signal and some spectral distortions are interpreted as natural, perceptually non-annoying ones [9].

L.S.B. Coding, echo Coding, Phase Coding, Quantization index modulation, spread spectrum modulation and adding watermark by modifying the coefficient of various transform (F.F.T., D.C.T., D.W.T.) are various algorithm of audio watermarking. Every algorithm has its own advantages and disadvantages hence the choice of any algorithm depends on our requirements and applications. Again watermarking can be done in time domain or in transformed domain in time domain a watermarked signal is directly added to the audio file the main advantage of time domain is that it is simple, low cost method, less complexity and has fast speed the main drawback of time domain methods are that these methods are less robust against various signal processing attacks like compression, filtering etc. again in time domain method to maintain the perceptual quality of watermarked signal the shaping of watermark is essential before watermark embedding. In transformed domain audio watermarking the watermarking is more robust against various signal processing attacks but somewhere more complex. In the transformed domain the signal is first transformed to process essential information from the signal the most common transforms are F.F.T., S.T.F.T., D.W.T, and D.C.T. in transformed domain audio watermarking the coefficients of various transform are modified (Quantized) according to the watermark signal.

## Transformation Techniques

### Discrete Fourier Transform

Discrete Fourier transform convert time domain signal (time verses amplitude plot) in to the frequency domain signal (frequency verses amplitude plot). Frequency domain gives information about that what frequency components present in a given signal and what are the amplitude of these frequency components. But it gives no idea that at time axis where these frequency components exist. So Fourier transform is a suitable tool only for stationary signals( signals in which frequency does not changes w.r.t. time)but it is not a suitable tool for non stationary signal(in which frequency changes w.r.t. time) Hence Fourier transform provide good frequency resolution but poor time resolution.

### Sort Time Fourier Transform

Sort Time Fourier Transform is a modified version of Fourier transform stft is simply a Fourier transform of a signal but multiplied by a window function of finite time duration(where as Fourier transform is calculated from  $-\infty$  to  $+\infty$ ). The main concept about the sort time Fourier transform is that a non stationary signal can be assumed stationary for a very sort time duration. The problem with STFT is with selection of the size of window. Narrow window will gives better time resolution whereas poor freq Resolution whereas wider window gives poor time resolution whereas good frequency resolution. In STFT once window size is chosen all frequency components are analysed with the same window. But the same window is not suitable for the analysis of all spectral components.

### Discrete Wavelets Transform

The Discrete Wavelets Transform provide powerful multi-resolution tool for the analysis of non-stationary signals with good time localization information [7] multi-resolution means The different window size is used for the different spectral components. Or we can say that we used different scale( $1/\text{frequency}$ ) for the analysis of different spectral components. Large scale is chosen for the analysis is small frequency components whereas small scale is chosen for the analysis of high frequency components. Time In discrete wavelet transform different scale is selected with the help of different cut off frequency filters. In dWT a signal (s) is passed through a low pass filter and high pass filter for decomposing the signal into approximate coefficient (C0) and detailed coefficients (D0) respectively. The approximate coefficient [C0 o/p of LPF (0)] is again passed through the

L.P.F (1). and H.P.F.(1) to decompose the approximate coefficient (C0) further in to approximate coefficient (C1) and detailed coefficient(D1) The number of decompositions in this process is usually determined by application and length of original signal. The data obtained from the above decomposition are called the DWT coefficients. Moreover, the original signal can be reconstructed from these coefficients. This reconstruction is called the inverse DWT [6]. The process of decomposition is shown in figure 1.

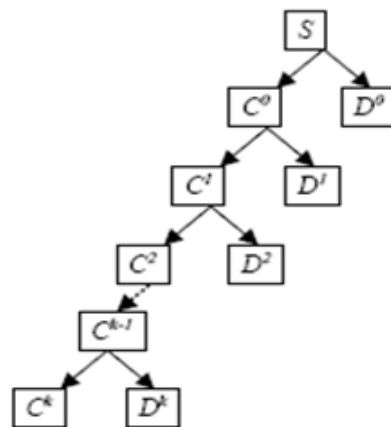


Figure 1: Decomposition of Original Signal into Wavelet Coefficients

## Discrete Cosine Transform

DCT is a transform representing a signal in the form of a series of coefficients obtained from a sum of cosine functions oscillating at different frequencies and at different amplitudes [3]. DCT is a Fourier-related transform similar to the discrete Fourier transform (DFT), but using only real numbers. DCT are equivalent to DFT of roughly twice the length, operating on real data with even symmetry There are eight standard DCT variants, of which four are common. The most common variant of discrete cosine transform is the type-II DCT, which is often called simply the DCT; its inverse, the type-III DCT, is correspondingly often called simply the inverse DCT or the IDCT [5].

$$y(k) = w(k) \sum_{n=0}^{N-1} x(n) \cos \frac{\pi(2n-1)(k-1)}{2N} \quad (1)$$

for  $k = 0, 1, 2, 3, \dots, N-1$ . Similarly, the inverse transformation is defined as:

$$x(n) = \sum_{k=0}^{N-1} w(k)y(k)\cos\frac{\pi(2n-1)(k-1)}{2N} \quad (2)$$

for  $n = 0, 1, 2, 3, \dots, N-1$ . In both equations 1 and 2,  $w(k)$  is defined as:

$$w(k) = \begin{cases} \frac{1}{\sqrt{N}} & k = 0 \\ \sqrt{\frac{2}{N}} & 1 \leq k \leq N-1 \end{cases} \quad (3)$$

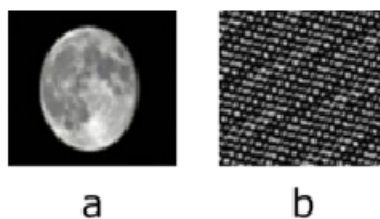
The D.C.T. has energy companding prosperity i.e. Ability in compressing energy of the signal in few coefficients is one of the criteria for comparing performance of the transforms. Now D.C.T. has becomes the standard for data compression.

### Arnold Transform

Arnold's transformation, convert an image to its scrambled version (randomizes the original organization of its pixels). However, if iterated enough times, eventually the original image reappears. The number of iterations taken is known as the Arnold's period. The period depends on the image size; i.e. for different size images, Arnold's period will be different [8].

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \text{ mod } n \quad (4)$$

Where,  $n$  is the size of image Figure 2(a) shows the original image and Figure 2(b) shows the Arnold's encrypted image.



**Figure 2:** (a) Shows the original image and (b) Shows the Arnold's encrypted image.

## Proposed Algorithm

The algorithm we are going to Propose takes advantages of both D.W.T. and D.C. T. The main advantage of D.W.T. is multi-resolution analysis and better spectral localization, whereas the main advantage of D.C.T. is its energy companding property i.e. ability in compressing energy of the signal in few coefficients.

Audio watermarking algorithm can be divided into the parts:

1. Watermark Preprocessing
2. Watermark Embedding Algorithm
3. Watermark Extraction Algorithm

### Watermark Preprocessing

A watermark (gray scale image) can not be directly added to the audio signal first we need to process (gray image) our watermark. Watermark preprocessing has the following steps:

**Step 1:** Convert gray-scale watermark image into two dimensional matrix whose size is  $M \times N$ .

Image = [Image (j, k), ( $0 \leq j < M$ ), ( $0 \leq k < N$ )]

**Step 2:** Convert gray scale watermark image into binary image.

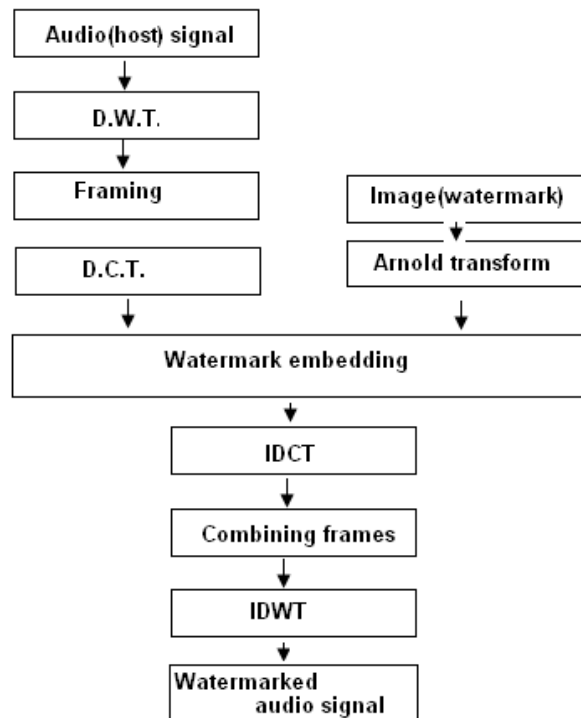
**Step 3:** By taking Arnold transform we can scramble the watermark image and get scrambled image.

**Step 4:** Convert Two dimensional image matrix into one dimensional image vector  $W$  of length  $M \times N$ .

$W = [w(i) = \text{Image}(j,k), 0 \leq i < M \times N, 0 \leq j < M, 0 \leq k < N]$



## Watermark Embedding Algorithm



**Figure 3:** *Watermark Embedding Algorithm*

**STEP 1:** First we decompose the original audio signal with the discrete wavelet transform up to  $i$  level. After the wavelet decomposition we get the approximate coefficient  $A_i$  and Detailed coefficient  $D_i, D_{i-1}, D_{i-2}, D_{i-3}, D_1$ . Where,  $i$  is the level of decomposition.

**STEP 2:** Select the low frequency coefficient of decomposed signal  $A_i$  and these approximate coefficient are then converted into non overlapping frames.

**STEP 3:** Apply D.C.T. to each frames and calculate D.C.T. coefficients.

**STEP 4:** The energy of each frame is calculated by using following equation:

$$\text{Energy} = \sum_i |V(i)|^2 \quad (5)$$

**STEP 5:** With the help of peak detection algorithm the prominent peaks from

the highest energy frames are fined and then watermark is embedded into selected N peaks of highest energy frames using the following equation:

$$V_i^w = V_i(1 + \alpha X_i) \quad (6)$$

Where,

$V_i^w$  = adjusted magnitude coefficient (watermarked magnitude coefficients),

$V_i$  = magnitude coefficient into which watermark to be embedded,

$X_i$  = watermark to be embedded with V,

$\alpha$  = scaling factor decide the strength of watermarking.

STEP 6: Apply the inverse discrete cosine transform to each frames .

STEP 7: Combine each frames.

STEP 8: Applied IDWT for getting watermarked audio signal.

### Watermark Extraction Algorithm

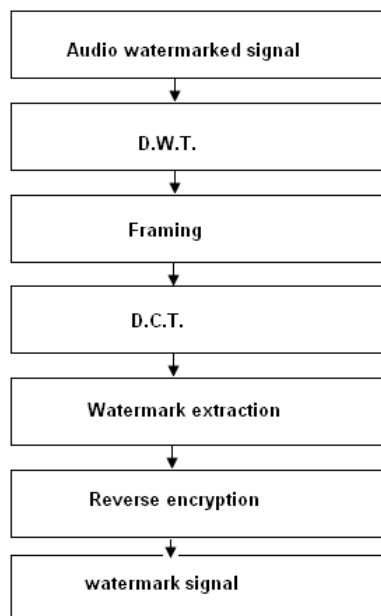


Figure 4: Watermark Extraction Algorithm

**STEP 1:** First we decompose the original audio signal with the discrete wavelet transform up to  $i$  level. After the wavelet decomposition we get the approximate coefficient  $A_i$  and Detailed coefficient  $D_i, D_{i-1}, D_{i-2}, D_{i-3}, D_1$ . Where,  $i$  is the level of decomposition. Here we choose  $i = 3$ .

**STEP 2:** Select the low frequency coefficient of decomposed signal  $A_i$  and these approximate coefficient are then converted into non overlapping frames.

**STEP 3:** Apply D.C.T. to each frames and calculate D.C.T. coefficients.

**STEP 4:** The energy of each frame is calculated by using following equation:

$$\text{Energy} = \sum_i |V(i)|^2 \quad (7)$$

**STEP 5:** Extract the highest prominent peaks from the D.C.T. coefficients. Which are located at the same position in the embedding process with the help of peak detection algorithm.

**STEP 6:** With the help of watermark extraction algorithm the watermark vector can be calculated with the help of following equation:

$$X_i^* = \frac{\frac{V_i^w}{V_i} - 1}{\alpha} \quad (8)$$

**STEP 7:** Convert extracted watermark vector back into scrambled image.

**STEP 8:** The original image of binary format can be obtained by applying an Arnold transform.

**STEP 9:** Again convert binary image to gray image.

## Simulation and Results

In this section the performance of our proposed watermarking scheme is evaluated. The imperceptibility is measured in terms of signal to noise ratio, the robustness can be measured in terms of normal correlation. For checking the performance of audio watermarking five different type of 16 bit MONO audio signals S1, S2, S3, S4 and S5 are considered which were sampled at the rate of 44.1 KHZ. 15 x 15 gray scale image is used as a watermark as shown in figure. The size of watermark is depend on the length of audio signal.

## Performance Parameters

The performance parameters for the proposed algorithms are S.N.R.(Signal to noise ratio) for imperceptibility and Normalized correlation for robustness.

### Imperceptibility

To measure imperceptibility, we use Signal-to-Noise ratio (SNR) as an objective measure. Imperceptibility is related to the perceptual quality of the watermarked signal. It ensures that the quality of the signal is not perceptible to a listener. The Signal to noise ratio can be defined As the ratio of Signal Power to the Noise power:

$$\text{SNR} = \frac{S_{\text{signal}}}{P_{\text{noise}}} \quad (9)$$

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

$$\text{SNR} = 10 \log_{10} \left[ \frac{\sum_{n=1}^N S^2(n)}{\sum_{n=1}^N [S(n) - S'(n)]^2} \right] \quad (10)$$

Where,  $S(n)$  is a host audio signal of length N samples and  $S'(n)$  be watermarked audio signal.

### Results Imperceptibility (Perceptual Quality Test)

**Table 1:** S.N.R. for various signals and at different values of  $\alpha$

Type of Signal	S.N.R. ( $\alpha=0.1$ )	S.N.R. ( $\alpha=0.2$ )	S.N.R. ( $\alpha=0.3$ )
S1	26.06	22.16	19.40
S2	26.29	22.23	20.10
S3	26.93	23.06	20.96
S4	27.12	23.10	21.43
S5	29.44	24.34	21.90

The listening test as a **subjective measure** The inaudibility of our watermarking method has been done by listening tests involving ten persons. Each listener was presented with the pairs of original signal and the watermarked signal and was asked to report whether any difference could be detected between

the two signals. The ten people listed to each pair for 10 times and they have a grade for this pair, using the ITU-R BS.1284 standardized 5-point grading scale [4]. The average grade for of each pair from all listeners is the final grade for this pair.

**Table 2:** *ITU-R grading for our watermarking scheme*

Grade	Quality	Imperceptibility test
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad Very	Annoying

The subjective measure of imperceptibility is done by listening test Average ITU-R grade value of the proposed watermarking system is shown in table 3.

**Table 3:** *Grading Scale (ITU-R)*

Type of signal	ITU-R Grade ( $\alpha=0.1$ )	ITU-R Grade ( $\alpha=0.2$ )	ITU-R Grade ( $\alpha=0.3$ )
S1	5	5	5
S2	5	5	5
S3	5	5	5
S4	5	5	5
S5	5	5	5

## Robustness

Normalized Correlation (N.C.) can be a more sensible measure for expressing the robustness of the audio watermarking algorithm against various signal processing attacks like Re sampling, Re quantization, Compression, low pass filtering, cropping etc. some times. Correlation is the measure of similarity between two signals. Correlation can be measured by using normalized signal which is termed as normalized correlation Normal correlation can be calculated

as:

$$NC = \frac{\sum_{i=1}^P \sum_{j=1}^Q w(i, j)w'(i, j)}{\sqrt{\sum_{i=1}^P \sum_{j=1}^Q w^2(i, j)} \sqrt{\sum_{i=1}^P \sum_{j=1}^Q w'^2(i, j)}} \quad (11)$$

In above equation  $w$  and  $w'$  are original and extracted watermarks and  $i$  and  $j$  are indexes of watermark image. and the size of  $w$  and  $w'$  is  $P \times Q$  In fact, by setting a threshold value for NC, the receiver can decide whether the extracted watermark correlates (is similar) with the signature embedded watermark. The robustness of the watermark is tested for the following attacks.

**MP3 COMPRESSION 64 KBPS:** The MPEG-1 layer-3 compression is applied. The watermarked audio signal is compressed at the bit rate of 64 kbps and then decompressed back to the wave format. [Refer Table 4]

**RE-SAMPLING:** The watermarked signal, originally sampled at 44.1 kHz, is re-sample at 22.05 kHz, and then restored back by sampling again at 44.1 kHz. [Refer Table 5]

**RE-QUANTIZATION:** The 16-bit watermarked audio signal is re-quantized down to 8 bits/sample and then back to 16 bits/sample. [Refer Table 6]

**ADDITIVE WHITE GAUSSIAN NOISE (AWGN):** White Gaussian noise is added to the watermarked signal until the resulting signal has an SNR of 15 dB. [Refer Table 7]

**LOW-PASS FILTERING:** A second-order Butterworth filter with cut-off frequency 4 kHz is used. [Refer Table 8]

**CROPPING:** 10% segments are removed from the watermarked audio signal at the beginning and subsequently replaced by segments of the original signal. [Refer Table 9]

**Table 4:** Normalized Correlation after MP3 Compression

Type of signal	Normalized Correlation ( $\alpha=0.1$ )	Normalized Correlation ( $\alpha=0.2$ )	Normalized Correlation ( $\alpha=0.3$ )
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	0.978	1	1
S5	0.997	1	1

**Table 5:** Normalized Correlation after Re-sampling

Type of signal	Normalized Correlation ( $\alpha=0.1$ )	Normalized Correlation ( $\alpha=0.2$ )	Normalized Correlation ( $\alpha=0.3$ )
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	0.988	1	1
S5	1	1	1

## Conclusions, Results Analysis and Future Work

As the value of  $\alpha$  is increasing the value of signal to noise ratio decreasing but the value normalized correlation increased and vice versa so there is a trade off between imperceptibility and robustness. Again the simulation result of proposed algorithm for imperceptibility requirement is very good according to IFPI (International Federation of the Phonographic Industry) standard For all the signals and for different value of  $\alpha$  the SNR has always been above 25 dB which shows good quality of watermarked signal according to IFPI the S.N.R. of audio signal should be above 20 dB.

Again the watermark is very robust again various type of signal processing attacks normal correlation shows the degree of similarity between the embedded

**Table 6:** *Normalized Correlation after Re-quantization*

Type of signal	Normalized Correlation ( $\alpha=0.1$ )	Normalized Correlation ( $\alpha=0.2$ )	Normalized Correlation ( $\alpha=0.3$ )
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	1	1	1
S5	1	1	1

**Table 7:** *Normalized Correlation after AWGN*

Type of signal	Normalized Correlation ( $\alpha=0.1$ )	Normalized Correlation ( $\alpha=0.2$ )	Normalized Correlation ( $\alpha=0.3$ )
S1	1	1	1
S2	1	1	1
S3	0.998	1	1
S4	1	1	1
S5	0.967	1	1

watermark and extracted watermark the value of normal correlation is always 1 for the value of  $\alpha = 0.2$  and  $\alpha = 0.3$  for all the signals. For the value of  $\alpha = 0.1$  it is always very close to one. The simulation results shown above in the table prove that the proposed method is quite robust against various signal processing attacks as well as maintain very good perceptual quality. In future, we can embed the color image as a watermark. And add watermark simultaneously to the approximate and detailed coefficient to improve the robustness.



**Table 8:** *Normalized Correlation after Low-pass Filtering*

Type of signal	Normalized Correlation ( $\alpha=0.1$ )	Normalized Correlation ( $\alpha=0.2$ )	Normalized Correlation ( $\alpha=0.3$ )
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	0.966	1	1
S5	0.989	1	1

**Table 9:** *Normalized Correlation after Cropping*

Type of signal	Normalized Correlation ( $\alpha=0.1$ )	Normalized Correlation ( $\alpha=0.2$ )	Normalized Correlation ( $\alpha=0.3$ )
S1	1	1	1
S2	1	1	1
S3	1	1	1
S4	1	1	1
S5	0.998	1	1

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