



A Comparative Study of ECG Signal Compression Techniques Using Various Transforms

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Abstract— This paper presents a comparative study of different ECG signal compression techniques using different transforms to find the optimal technique to compress these signals to reduce their size and the cost of their storing and transmitting. The ECG signals downloaded from (MIT-BIH arrhythmias data base). Five different transform compression techniques investigated: Discrete Cosine Transform-I , Discrete Cosine Transform-II, Discrete Sine Transform, Fast Fourier Transform, and Wavelet Transform. The performance of these techniques was measured by two criteria: Compression Ratio, and Percentage Root Mean Square Difference. The obtained results show that the wavelet transform using the fourth order Daubechies function at the second decomposition level gives better performance Compression Ratio=96.8832, and Percentage Root Mean Square Difference =0.7981. All the compression techniques implemented and their performance evaluated using MATLAB (2013) program.

Keywords— Electrocardiogram, Discrete Cosine Transform, Discrete Sine Transform, and Fast Fourier Transform.

I. INTRODUCTION

An electrocardiogram (ECG) is simply a representation of the electrical activity of the heart muscle as it changes with time, usually printed on paper for easier analysis. Like other muscles, cardiac muscle contracts in response to electrical depolarization of the muscle cells. It is the sum of this electrical activity, when amplified and recorded for just a few seconds that we know as an ECG [1]. There is an exponential increase in digital data, obtained from various signals specially the biomedical signals such as (ECG), electroencephalogram (EEG), electromyogram (EMG) etc. How to transmit or store these signals efficiently becomes the most important issue. Transmission techniques of these biomedical signals through communication channels is an important issue as it allows experts to make a remote assessment of the information carried by the signals, in a very cost effective way. Storage of these bio-medical signals leads to a large volume of information, thus the necessity of efficient data compression methods for biomedical signals is currently widely recognized [2]. The central goal of (ECG) data compression is to achieve a reduced information rate, while preserving the relevant diagnostic information in the reconstructed signal. A data compression algorithm should allow reconstruction of the data with acceptable fidelity [2].

II. ECG SIGNAL COMPRESSION TECHNIQUES

The conventional ECG compression techniques can be categorized into: direct time-domain techniques, transformed frequency domain techniques [3].

1. Direct Time-Domain Techniques

A direct method performs the compression directly on the ECG signal. These are also known as time domain techniques. To get a high performance time domain compression algorithm, intelligent sample selection criteria should be used. The original signal is reconstructed by an inverse process, often by drawing straight lines between the extracted samples. The key to a successful algorithm is the development of a good rule for determining the most significant samples [3]. The direct methods are highly sensitive to sampling rate, quantization levels, and high frequency interference [4].

2. Transformed Frequency Domain Techniques

They divide the signal into frequency components and allocate bits in the frequency domain efficiently. The input signal is divided into blocks of data and then stored in the frequency domain in the form of a vector. Then the entries in the vector are de-correlated which helps one to retain only the useful information. Their main focus is to minimize the number of addition and multiplication operations by using the symmetry property of the transformation techniques for ECG signal compression is evaluated and compared. The various compression techniques have been discussed below:

A. Discrete Cosine Transform-I (DCT-I)

DCT is closely related to DFT. It transforms a signal from spatial representation into frequency representation. DCT represents a signal as a sum of varying magnitude and frequency. It implies different boundary condition and often used in signal and image processing for lossy data compression has strong “energy compaction property” and it provide high de-correlation [5]. The DCT-I equation as follow: [5]

$$Y(k)=w(k)\sum_{n=1}^N x(n) \cos (\pi(2n - 1)(k - 1)/2N) \quad \dots(1)$$

Where:

$$k=1,2,\dots,N$$

$$w(k)=1/\sqrt{N} \quad k=1$$

$$w(k)=2/\sqrt{N} \quad 2 \leq k \leq N$$

B. Discrete Cosine Transform-II (DCT-II)

The DCT-II is the most commonly used form, and is often simply referred to as "the DCT". This transform is exactly equivalent (up to an overall scale factor of 2) to a DFT of 4N real inputs of even symmetry where the even-indexed elements are zero [5]. That is, it is half of the DFT of the 4N [5]:

$$X_k=\sum_{n=0}^{N-1} X_n \cos\left(\frac{\pi}{N}\left(n + \frac{1}{2}\right) k\right) \quad \dots(2)$$

Where:

$$k=1,2,\dots,N.$$

The DCT-II implies the boundary conditions: x_n is even around $n=-1/2$, and even around $n=N-1/2$; X_k is even around $k=0$ and, odd around $k=N$.

C. Discrete Sine Transform (DST)

DST is fourier related transform similar to discrete fourier and it uses purely matrix. It implies different boundary conditions [6]. The DST is implemented by equation (3) [6]:

$$Y(x)=\sum_{n=0}^{N-1} X_n \sin\left(\frac{\pi kn}{N+1}\right) \quad \dots(3)$$

Where:

$$X=1,2,\dots,N.$$

D. Fast Fourier Transform (FFT)

A fast fourier transform is an efficient algorithm to compute the discrete Fourier transform (DFT) and it's inverse. There are many distinct FFT algorithms involving a wide range of mathematics, from simple complex- number arithmetic to group theory and number theory. An FFT is a way to compute the same result more quickly. Computing a DFT of 2N points in the naive way, using the definition, takes $O(N^2)$ arithmetical operations, while an FFT can compute the same result in only $O(N \log N)$ operations. The difference in speed can be substantial, especially for long data sets where N may be in the thousands or millions—in practice, the computation time can be reduced by several orders of magnitude in such cases, and the improvement is roughly proportional to $N / \log(N)$. This huge improvement made many DFT-based algorithms practical; FFTs are of great importance to a wide variety of applications, from digital signal processing and solving partial differential equations to algorithms for quick multiplication of large integers. The most well known FFT algorithms depend upon the factorization of N, but there are FFTs with $O(N \log N)$ complexity for all N, even for prime N. Many FFT algorithms only depend on the fact that is an Nth primitive root of unity, and thus can be applied to analogous transforms over any finite field, such as number-theoretic transforms. Fast Fourier Transform is a fundamental transform in digital signal processing with applications in frequency analysis, signal processing etc [7].

III. DISCRETE WAVELET TRANSFORM (DWT)

Recently developed wavelet transforms have become an attractive and efficient tool in many applications especially in coding and compression of signals. This results from their multi-resolution and high energy compaction properties. Wavelet transform can be viewed as a block transform with overlapping basis functions of variable lengths. Using WT the time domain signal $x(t)$ can be expanded in terms of a weighted sum of a set of basis functions, in a way similar to the generalized Fourier series expansion. While for the classical Fourier series the basis functions are sine and cosine functions at different frequencies, in the case of wavelet series, the basis functions $\Psi_{j,k}(t)$ are translations and dilations of a single fixed function $\Psi(t)$ called the mother wavelet [8]:

$$\Psi_{j,k}(t)=2^{\frac{j}{2}} \Psi (2^j t-k), j,k \in Z \quad \dots(4)$$

For certain choices of $\Psi (t)$, the corresponding set of $\Psi_{j,k}(t)$ forms an orthonormal basis in $L_2(R)$. In this case: [8]

$$X(t)=\sum_j \sum_k d_{j,k} \Psi_{j,k}(t) \quad \dots(5)$$

Where the wavelet coefficients $d_{j,k}$ are calculated using the relation [8]:

$$d_{j,k}=\int x(t) \Psi_{j,k}(t) dt = 2^{\frac{j}{2}} \int x(t) \Psi (2^j t-k) dt \quad \dots(6)$$

In contrast to the sine and cosine, wavelets are local in frequency/scale via dilations and in time via translations. This localization offers an advantage, since fewer wavelet basis functions are usually needed to represent the $x(t)$ to a given level of approximation. This property is of great importance in the compression of the signal [8].

IV. PERFORMANCE EVALUATION

Any performance criterion used to evaluate an ECG compression algorithm must include two factors Compression ratio, (CR) and Percent root mean square difference, (PRD) [7]. In this paper the performance of the compression techniques is evaluated based on these two factors.

1. Compression Ratio (CR)

Compression efficiency is measured by the compression ratio. The compression ratio (CR) is defined as the ratio of the number of bits representing the original signal to the number of bits required to store the compressed signal [9]. The CR can be calculated using equation (7) [6]:

$$\text{Compression Ratio} = \frac{\text{size after compression}}{\text{size before compression}} \dots\dots\dots(7)$$

2. Percentage Root Mean Difference (PRD)

Percentage root mean difference measures distortion between the original signal and the reconstructed signal [2]. PRD can be defined as the following: [2]

$$\text{PRD} = \sqrt{\frac{\sum_{n=1}^N [x1(n) - x2(n)]^2}{\sum_{n=1}^N x1(n)^2}} * 100 \dots\dots\dots(8)$$

Where $x1(n)$: original signal of length N ,and $x2(n)$: reconstructed signal of length N . The PRD which is an error measurement indicates reconstruction fidelity by point wise comparison with the original data [2].

V. RESULTS AND DISCUSSION

The physiobank ATM database has been used to test the performance of the five compression techniques presented in this paper. The amount of compression is measured by CR and the distortion between the original and reconstructed signal is measured by PRD. Figure (1) shows the Comparison of compression ratios for the five compression techniques. The two highest compression ratios that obtained are : 96.8832 for WT technique, and 95.6421 for DCT-II technique, while the lowest compression ratio is 85.1800 for DST technique. Figure (2) shows the Comparison of PRD values for the five compression techniques. The two lowest PRD values that obtained are: 0.7981 for WT technique, and 0.9382 for DCT-I technique, while the highest PRD is 1.3319 for DCT-II technique. Table (1), details the resultant compression techniques. This gives the choice to select the best suitable compression technique. The higher values of PRD indicates higher distortion of the reconstructed ECG signal. Although the DCT-II technique provides high compression ratio, but it suffers from high PRD value. The WT compression technique exhibited a high degree of robustness (highest CR, and lowest PRD), when compared to the others techniques. In this technique it is important to choice the right wavelet function that provides perfect reconstruction of the ECG signal. The fourth order Daubechies wavelet function (DB4) is used in this paper because it is most matching the ECG signal’s shape this will guarantee the perfect reconstruction of the ECG signal. Figure (3) shows the shape of DB4 wavelet function. Finally figure (4) shows the Comparison between original and decompressed (reconstructed) ECG signal using WT technique, also it shows the error signal for all samples of the ECG signal.

VI. CONCLUSIONS

From the obtained results it can be concluded that the WT compression technique provides better performance than the others ECG signal compression techniques presented in this paper. The WT compression technique achieved a good balance between the degrees of compression (highest CR value) and residual distortion (lowest PRD value).

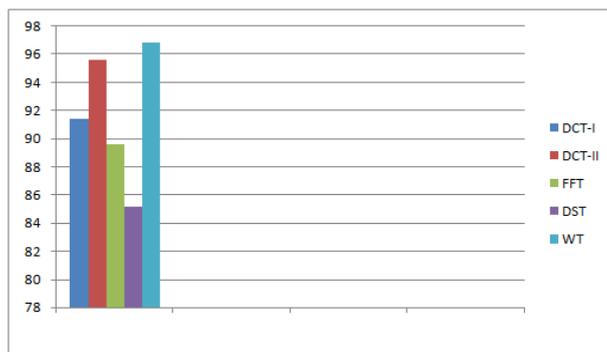


Fig. 1 Comparison of compression ratios for the five compression techniques.

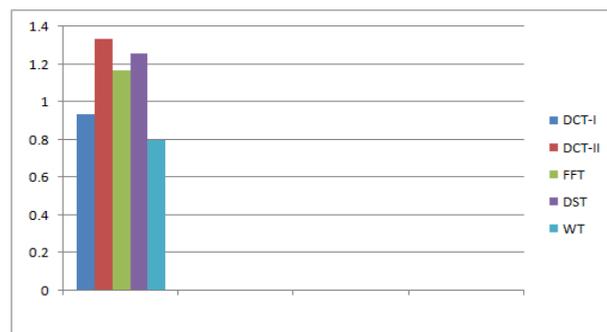


Fig. 2 Comparison of PRDs for the five compression Techniques.

Table I Detailed Results for the Different Compression Techniques.

Compression Technique	Compression Rate (CR)	Percentage Root Mean Square Difference (PRD)
DCT-I	91.4400	0.9382
DCT-II	95.6421	1.3319
FFT	89.5700	1.1661
DST	85.1800	1.2589
WT (DB4, Decomposition Level=2)	96.8832	0.7981

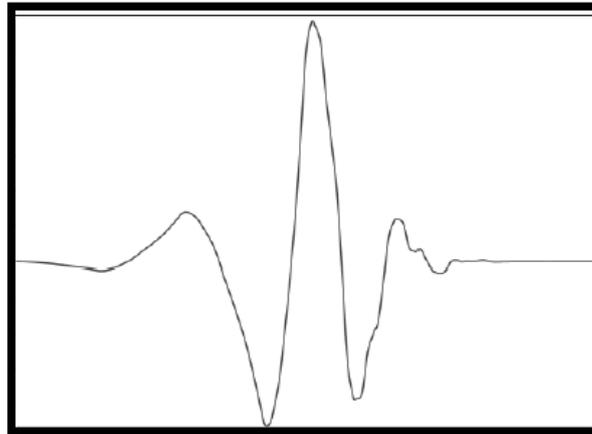


Fig. 3 DB4 wavelet function.

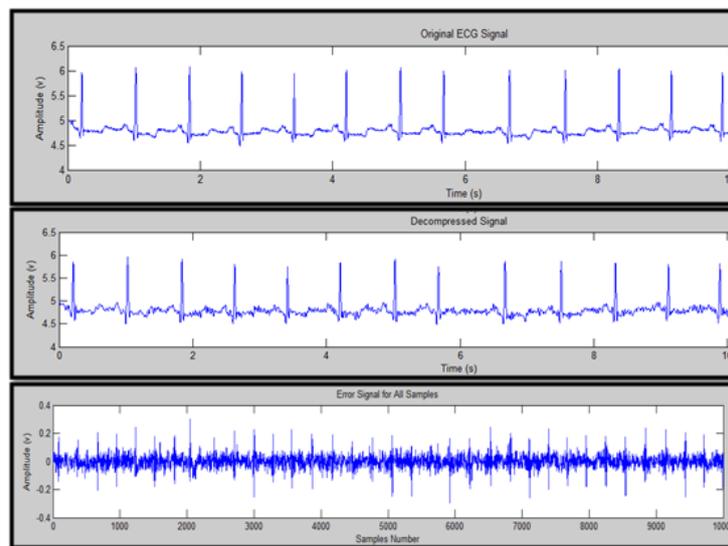


Fig. 4 Comparison between Original and Decompressed ECG Signal Using WT Technique.

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