ECG Signal Compression Using Different Techniques

K. Ranjeet, A. Kumar, and R.K. Pandey

Indian Institute of Information Technology Design and Manufacturing,
Jabalpur-482005, MP (India)
ranjeet281@gmail.com, anilkdee@gmail.com,
wavelet_r@yahoo.co.in

Abstract. In this paper, a transform based methodology is presented for compression of electrocardiogram (ECG) signal. The methodology employs different transforms such as Discrete Wavelet Transform (DWT), Fast Fourier Transform (FFT) and Discrete Cosine Transform (DCT). A comparative study of performance of different transforms for ECG signal is made in terms of Compression ratio (*CR*), Percent root mean square difference (*PRD*), Mean square error (*MSE*), Maximum error (*ME*) and Signal-to-noise ratio (*SNR*). The simulation results included illustrate the effectiveness of these transforms in biomedical signal processing. When compared, Discrete Cosine Transform and Fast Fourier Transform give better compression ratio, while Discrete Wavelet Transform yields good fidelity parameters with comparable compression ratio.

Keywords: ECG, Compression, DWT, DCT, Huffman encoding, FFT.

1 Introduction

An electrocardiogram (ECG) is the graphical representation of electrical impulses due to ionic activity in the cardiac muscles of human heart. It is an important physiological signal which is exploited to diagnose heart diseases because every arrhythmia in ECG signals can be relevant to a heart disease [1, 2]. ECG signals are recorded from patients for both monitoring and diagnostic purposes. Therefore, storage of computerized is become necessary. However, the storage has limitation which made ECG data compression as an important issue of research in biomedical signal processing. In addition to these, there are many advantages of ECG compression such as transmission speed of real-time ECG signal is enhanced and is also economical.

An ECG signal contains steep slopes QRS complexes and smoother P and T waves. It is recorded by applying electrodes to various locations on the body surface and connecting them to a recording apparatus. There are certain amounts of sample points in ECG signal which are redundant and replaceable. ECG data compression is achieved by elimination of such redundant data sample points. Therefore, in early stage of research, several methods for ECG compression were introduced to achieve good compression ratio with preserving the relevant signal information. These algorithms were classified into three categories [3]: dedicated techniques such as AZTEC, FAN, CORTES, and turning point. These techniques were based on the detection and elimination of redundancies on direct analysis of the original signal, and

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gives minimum distortion. In second category, all transform based techniques comes and compression is achieved based on spectral and energy distribution of the signal. Other hand, last technique is based on feature and parameter extraction in which some parameter such as measurement of probability distribution of original signal is extracted. During last the two decades, several efficient methods [4-9] have reported in literature, which involve compression of ECG signal without losing and preserving the relevant clinical information for the accurate detection and classification.

In past, researches have proposed many transform methods such as Discrete Cosine Transform (DCT), Fast Fourier Transform (FFT) and Discrete Wavelet Transform (DWT), due to that, there is drastically changed in the field of data compression. FFT is a discrete Fourier transform (DFT) algorithm which reduces the number of computations needed for N points from $2N^2$ to $2N\log_2 N$ [10]. DFT is used in Fourier analysis of a signal in frequency domain. Based on FFT, many methods [10, 11] have been proposed for analyzing and compressing ECG signal. The discrete cosine transform is widely exploited for data compression such as speech compression, image compression and ECG compression. DCT is calculated using the FFT algorithm as it is DFT. However, DCT gives the more weight to low-pass coefficients to high-pass coefficients. DCT gives nearly optimal performance in the typical signal having high correlations in adjacent samples. Several researchers [12-16] have developed unique algorithms for compression of ECG signal based on Discrete Cosine Transform. The detailed discussion on FFT and DCT for ECG compression is given in [10-16] and the references there in.

During the last decade, the Wavelet Transform, more particularly Discrete Wavelet Transform has emerged as powerful and robust tool for analyzing and extracting information from non-stationary signal such as speech signal and ECG signal due to the time varying nature of these signals. Non-stationary signals are characterized by numerous abrupt changes, transitory drifts, and trends. Wavelet has localization feature along with its time-frequency resolution properties which makes it suitable for analyzing non-stationary signals such as speech and electrocardiogram (ECG) signals. Recently, several other methods [17-25] have been developed based on wavelet or wavelet packets for compressing ECG signal.

In above context, therefore, this paper presents some new results based on transform technique such as DWT, FFT and DCT for ECG signal compression. The paper is organized as follows. A brief introduction has been provided in this section on the existing compression techniques of ECG signal. Section 2 discusses overview of different transforms such DWT, FFT and DCT. Section 3 presents the methodology of ECG compression based on these transforms. Finally, a comparison of results obtained with these transforms is carried out in Section 4, followed by concluding remarks in Section 5.

2 Techniques for ECG Signal Compression

In this paper, three transforms such FFT, DCT and DWT are employed for the ECG signal compression.

2.1 Fast Fourier Transform

A signal having periodic function of time can be analyzed or synthesized as a number of harmonically related to sine and cosine signals [10, 11]. A periodic signal $f(t)$ with period T_0 can be represented by Fourier series as

$$f(t) = A_0 + \sum_{n=1}^{\infty} a_n \cos(2\pi nt / T_0) + \sum_{n=1}^{\infty} b_n \sin(2\pi nt / T_0) \tag{1}$$

where, A_0 is the average, or mean value of signal a_n and b_n are the Fourier series coefficients. t is the time and n is the coefficient index. The above Fourier series coefficients are found by FFT.

$$f(t) = A_0 + \frac{1}{2}\sum_{n=1}^{\infty}(a_n - jb_n)e^{j2\pi nt/T_0} \tag{2}$$

$$= \sum_{n=1}^{\infty} \alpha_n e^{j2\pi nt/T_0} \tag{3}$$

where, α_n are complex coefficients. It is also expressed as

$$\alpha_n = \frac{1}{T_0}\int_{-T_0/2}^{T_0/2} f(t)e^{-j2\pi nt/T_0}dt \qquad \text{n}=0, \mp 1, \mp 2, ... \tag{4}$$

For the sampled periodic signal, the discrete-time complex coefficients of the series are:

$$\alpha_n = \frac{1}{N}\sum_{k}^{N-1} f(k)e^{j2\pi kn/N} \tag{5}$$

and

$$f(k) = \sum_{k}^{N-1} \alpha_n e^{-j2\pi kn/N} \tag{6}$$

where, k is the discrete time index. N is the number of ECG signal samples. From equations (1), (2) and (4) give the Fourier series coefficients of Eq. (5) calculated using FFT technique. Since the ECG signal decomposition is assumed to be time varying due to cardiac disorders, Eq. (5) must be performed on each detected cycle. Fourier series coefficients used to synthesize the original signal is computed using Eq. (6) [12].

2.2 Discrete Cosine Transform

DCT has widely used for the data compression. In the signal decomposition based on DCT algorithms has four essential steps: dividing a signal in N sub-parts; DCT computation for each block; Thresholding & Quantization of the DCT coefficients; and encoding of the quantized DCT coefficients.

Discrete cosine transform is defined as

$$X(n)=\left(\frac{1}{N}\right)^{\frac{1}{2}}\sum_{i=0}^{N-1}x(i)\cos\left[\frac{\pi n}{2N}(2j+1)\right] \quad (7)$$

While the inverse IDCT is defined as:

$$x(i)=\left(\frac{1}{N}\right)^{\frac{1}{2}}\sum_{n=0}^{N-1}X(n)\cos\left[\frac{\pi i}{1N}(2n+1)\right] \quad (8)$$

DCT gives the decomposed coefficient of the original signal and it gives the more weight to low-pass coefficients to high-pass coefficients [12-16].

2.3 Discrete Wavelet Transform

Wavelets transform is a method to analyze a signal in time and frequency domain. DWT gives the multiresolution decomposition of a signal. There is three basic concept of multiresolution: subband coding, vector space and pyramid structure coding [18]. DWT decompose a signal at several *n* levels in different frequency bands. Each level decomposes a signal into approximation coefficients (low frequency band of processing signal) and detailed coefficients (high frequency band of processing signal) [19-25] as shown in Fig. 1

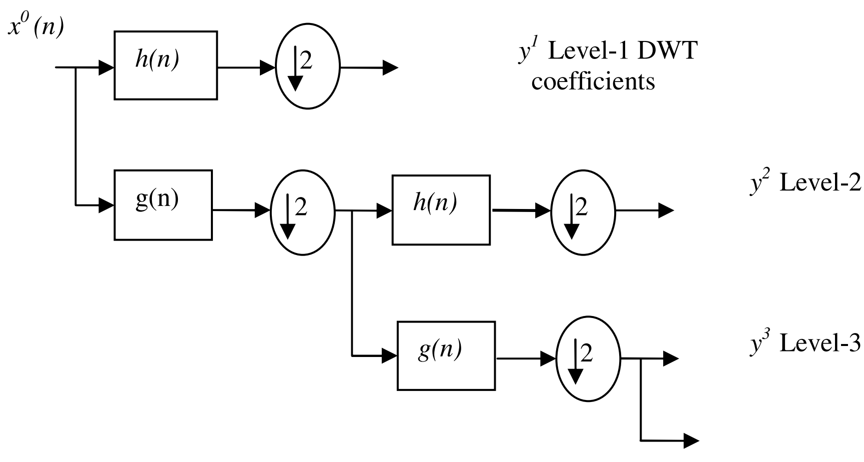


Fig. 1. Filter bank representation of DWT decomposition

At each step of DWT decomposition, there are two outputs: scaling coefficients $x^{j+1}(n)$ and the wavelet coefficients $y^{j+1}(n)$. These coefficients are given as

$$x^{j+1}(n)=\sum_{i=1}^{2n}h(2n-i)x^{j}(n) \quad (9)$$

and

$$y^{j+1}(n) = \sum_{i=1}^{2n} g(2n-i)x^{j}(n) \tag{10}$$

where, the original signal is represented by $x^0(n)$ and j show the scaling number. Here $g(n)$ and $h(n)$ represent the low pass and high pass filters, respectively. The output of scaling function is input of next level of decomposition, known as approximation coefficients. The approximation coefficients are low-pass filter coefficients and high-pass filter coefficients are detail coefficients of any decomposed signal.

3 Methodology for ECG Signal Compression

In this paper, the ECG compression is achieved using different transformation techniques such as FFT, DCT and DWT. The methodology of ECG compression based on transform is shown in Fig.2.

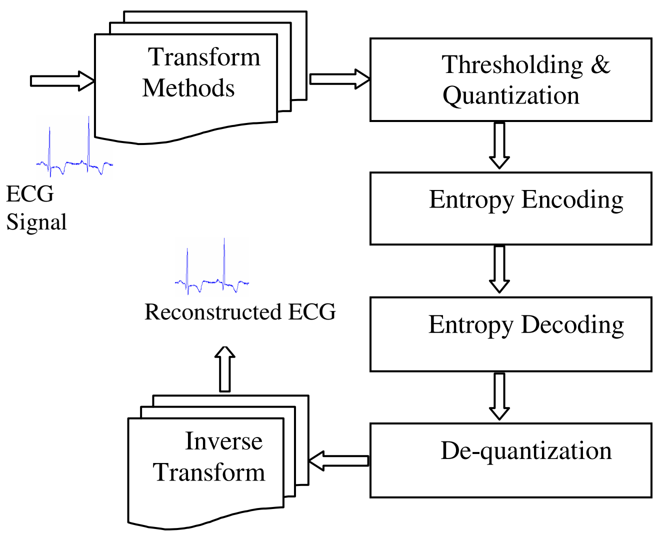


Fig. 2. Methodology for ECG signal compression

The algorithm of ECG compression is performing in three stages: (i) Transform calculation, (ii) Thresholding & Quantization, (iii) Entropy encoding. First, the signal (ECG signal) transformation is done with different transforms. Then, apply a threshold condition on the transform coefficients on the basis of energy packing efficiency of coefficients, which make a fixed percentage of coefficients equal to zero. Here, Global thresholding is used in which the threshold value is set manually, this value is chosen from transform analysis coefficient $(0\ldots.x_{max}^{j})$, where x_{max}^{j} is maximum coefficient. A detailed discussion on thresholding is given in [22, 24].

Further, uniform quantizer is employed on these coefficients. In quantization process, wavelet coefficients are quantized using uniform step size. The computation of step size depends on three parameters [13, 14]: maximum (M_{max}) and minimum (M_{min}) values in the signal matrix, and number of quantization level (L). Once these parameters are found, then step size (Δ)

$$\Delta = \left(M_{\max} - M_{\min}\right) / L \tag{11}$$

Then the input is divided into L+1 level with equal interval size ranging from M_{min} to M_{max} to plot quantization table. When quantization is done, then quantized values are fed to the next stage of compression and these three parameters defined above are stored in a file as they are required for creating the quantization table during reconstruction step. Detailed discussion on quantization is available in the references [6, 22, 24]. The actual compression is achieved at this stage and it is further achieved with the help of entropy encoding technique (Huffman). The quantized data contains same redundant data, means repeated data presents, it is waste of space. The way to overcoming this problem Huffman encoding is used. In this, the probabilities of occurrence of the symbols in the signal are computed. After that, these are arranged according to the probabilities of occurrence in descending order and build a binary tree and codeword table [24, 26, and 27]. Finally, compressed ECG signal is obtained.

4 Results and Discussion

In this paper, ECG signal compression is achieved using a methodology based on different transforms such as FFT, DCT and DWT. The performance of methodology algorithm can be evaluated by considering the fidelity of the reconstructed signal to the original signal. For this purpose, following fidelity assessment parameters [22-24] are considered:

Compression ratio (*CR*):

$$\mathrm{CR} = \frac{\text{Number of significant wavelet coefficients}}{\text{Total number of wavelet coefficients}} \tag{12}$$

Percent root mean square difference (*PRD*):

$$PRD = \left(\frac{\text{Reconstructed noise energy}}{\text{Origional signal energy}}\right)^{1/2} x\ 100\ \% \tag{13}$$

Mean square error (*MSE*):

$$MSE = \frac{1}{2}\sum_{n}\left|x(n) - y(n)\right|^{2} \tag{14}$$

Maximum error (*ME*):

$$ME = \max_{n}\left|x(n) - y(n)\right| \tag{15}$$

Signal to noise ratio (SNR):

$$SNR = 10\log_{10}\left(\frac{\text{energy of input signal}}{\text{energy of the reconstructed error}}\right)$$
$$=10\log_{10}\left\{\frac{\sum x^2(n)}{\sum |x(n)-y(n)|^2}\right\} \tag{16}$$

ECG records have been obtained from MIT-BIH Arrhythmia Database (Physionet Bank) [28]. Here, FFT, DCT and DWT are employed for same ECG signal (MIT BIH ECG record 100) and the simulation results obtained in each case are included in Table 1. In all three cases, global thresholding is applied. In case DWT, different wavelet filters such as Haar, db7, db10, bior3.5, coif3, coif4, and coif 5 are used for ECG compression. Fig. 3 shows the plot of the original ECG signals (MIT-BIH record 100) and its reconstructed version. While in Fig. 4, a comparative analysis of different transforms is depicted.

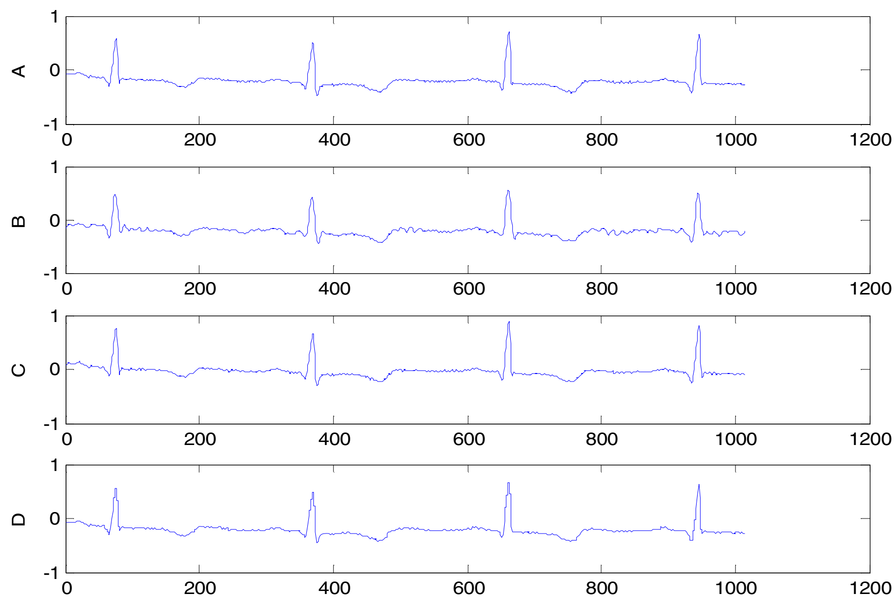
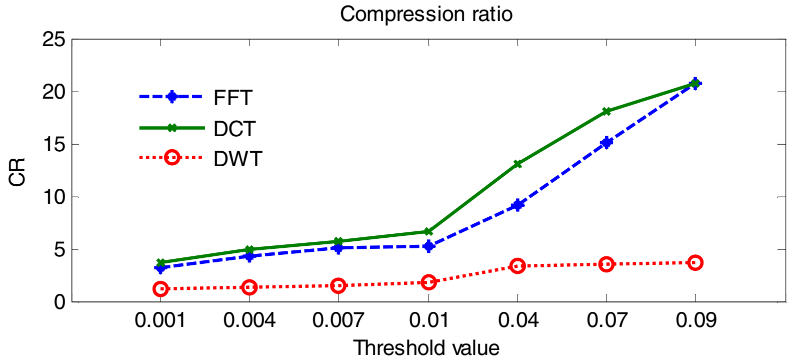
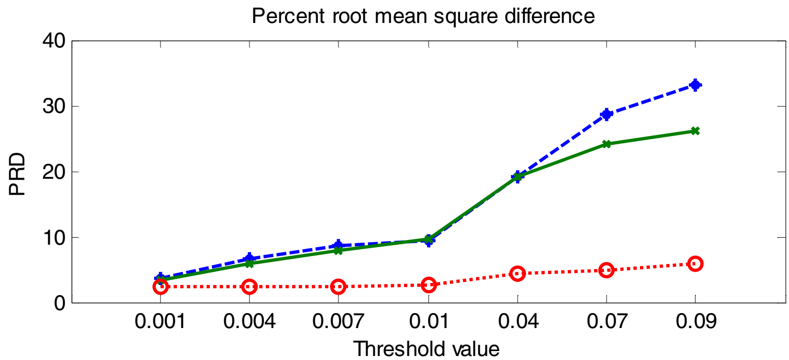


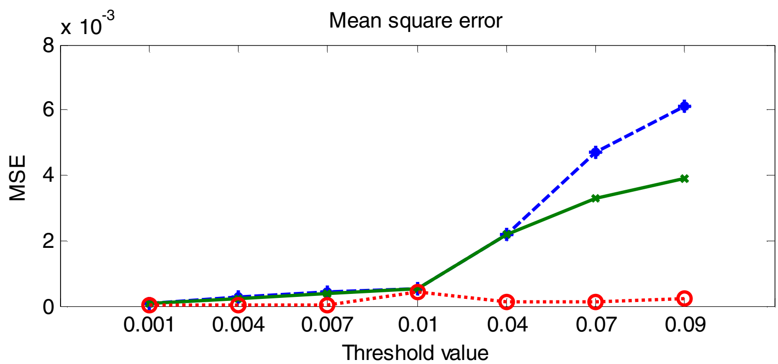
Fig. 3. (a) Original ECG signal, (b) Reconstructed signal using FFT, (c) Reconstructed signal using DCT, (d) Reconstructed signal using DWT



(a)

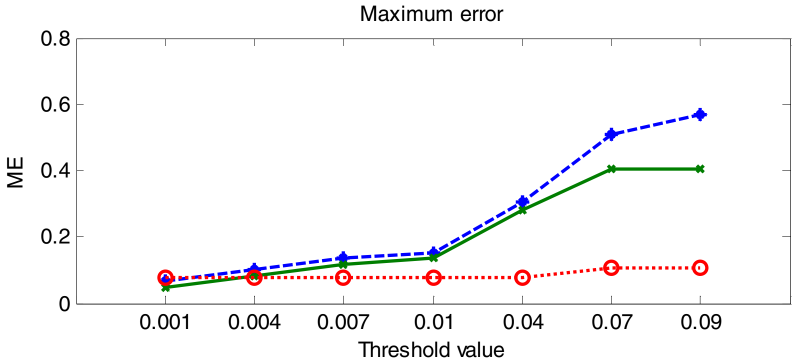


(b)

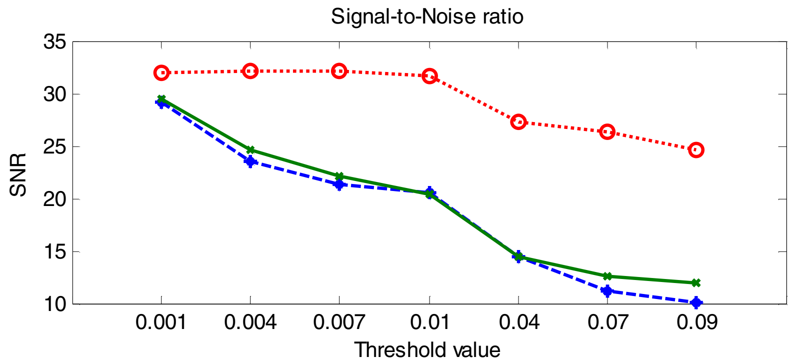


(c)

Fig. 4. A comparative analysis of the performance in different transforms(DCT, DWT and FFT) (a) Compression ratio (CR) (b) *PRD* (c) *MSE* (d) Maximum error (*ME*) (e) *SNR*



(d)



(e)

Fig. 4. (*continued*)

Table 1. Fidelity assessment parameters in different transforms

Type of Transform	***CR***	***PRD***	***MSE***	***ME***	***SNR***
FFT	5.31	9.34	5.32×10^{-4}	0.1537	20.62
DCT	6.58	9.53	5.45×10^{-4}	0.1353	20.45
DWT (Haar)	3.98	13.28	1.10×10^{-3}	0.2661	17.58
DWT (dB7)	3.86	9.55	5.47×10^{-4}	0.2269	20.43
DWT (dB10)	3.79	9.66	5.59×10^{-4}	0.2411	20.33
DWT (Bior 3.5)	3.88	11.68	8.05×10^{-4}	0.2660	18.75
DWT (Coif3)	3.81	8.46	4.34×10^{-4}	0.1788	21.43
DWT (Coif4)	3.76	8.28	4.15×10^{-4}	0.1714	21.62
DWT (Coif5)	3.68	8.17	4.062×10^{-4}	0.1680	21.72

It is evident from Table I and Fig. 4 that the good compression ratio can be obtained with these transforms with good fidelity measuring parameters. When compared, Discrete Cosine Transform and Fast Fourier Transform give better compression ratio, while Discrete Wavelet Transform yields good fidelity parameters with comparable compression ratio. The average compression ratio obtained in case of FFT and DCT are 5.31 and 6.58, respectively. While in case different wavelet filters, the compression ratio are 3.98, 3.86, 3.79, 3.88, 381, 376 and 3.68. Therefore, these transforms can be effectively used for ECG signal compression while preserving necessary clinical information.

5 Conclusions

In this paper, a transform based methodology is presented for ECG signal compression. A comparative study of performance of different transforms such as DCT, FFT and DWT for ECG compression is made. DWT decomposition is perfect to preserve clinical information, while DCT and FFT gives the high compression ratio. It is evident from the simulation results that these transforms can be effectively used for compression and analysis of ECG signal.

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