ECG Signal Compression using Different Wavelet Function

Conference Paper · December 2010

3 authors:

Ranjeet Kumar
VIT University Chennai

Anil Kumar
Indian Institute of information Technology Design and Manufacturing Jabalpur

Rajesh K. Pandey
Indian Institute of Technology (BHU) Varanasi

ECG Signal Compression using Different Wavelet Function

K. Ranjeet[1], A. Kumar[1] and Rajesh K. Pandey[1]
[1]*Indian Institute of Information Technology Design and Manufacturing, Jabalpur-482005, MP (India)*
(ranjeet281@gmail.com, anilkdee@gmail.com and wavelet_r@yahoo.co.in)

Abstract-In this paper, a wavelet based electrocardiogram (ECG) data compression technique is presented. This method employs different wavelet functions with variable length Huffman coding. A comparative study of performance of different wavelet and both types of thresholding (level and global) is made in terms of Signal-to-noise ratio (SNR), Peak signal-to-noise ratio (PSNR) and Normalized root-mean square error (NRMSE). The simulation results illustrates that good compression ratio can be found, while maintaining all clinical information.

Key Words- ECG, compression, wavelet, Huffman encoding

1. Introduction

Electrocardiogram (ECG) is the graphical representation of electrical impulses due to ionic activity in the cardiac muscles of human heart. ECG is played an important role to diagnose disease in heart because every arrhythmia in ECG signals can be relevant to a heart disease [1]. Normally one signal differs to other signal while sometimes one disease has dissimilar signs on different patient's ECG signals. ECG signals are recorded from patients for both monitoring and diagnostic purposes. ECG signal can be store as a digital data for further processing for Telemedicine applications. A huge amount of data is a big issue for storage or transmission. Therefore it is necessary to compress ECG signal to reduce the memory space in ECG data bases, and also reduces the transmission period of real time ECG signals over telephone networks for telemedicine application.

Several efficient methods [2-11] are available in literature which involve in compression schemes of ECG signal without losing and preserving the relevant clinical information for the accurate detection and classification. Generally, two types of compression schemes are exploited for ECG compression. These are direct and transform schemes [3]. In first scheme such as FAN, AZTEC, CORTES, and ASEC, the signal directly is coded and detailed discussion of these techniques is presented in [3]. Multi-resolution decomposition of signal is efficient for extract the content information [4]. In this technique, wavelet transform is optimal for the ECG processing and extracting the information. Recently, several other methods [5-12] have been developed based on wavelet or wavelet packets promise that it is a efficient power tool for compressing and analysis of ECG signal.
In this paper, therefore presents a comparative analysis of ECG compression using different wavelet function such as Haar wavelet, Debauches wavelet (db5, db7, db10) and B-spline wavelet (bior3.5) is presented.

2. Discrete wavelet transform

Wavelets transform is a method to analysis a signal in time and frequency domain, it is effective for the analysis of time-varying non stationary signal like ECG [13]. Wavelet transform give the multiresolution decomposition of signal. There is three basic concept of multiresolution: subband coding, vector space and pyramid structure coding [4]. 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 detail coefficients (high frequency band of processing signal) [4, 14].

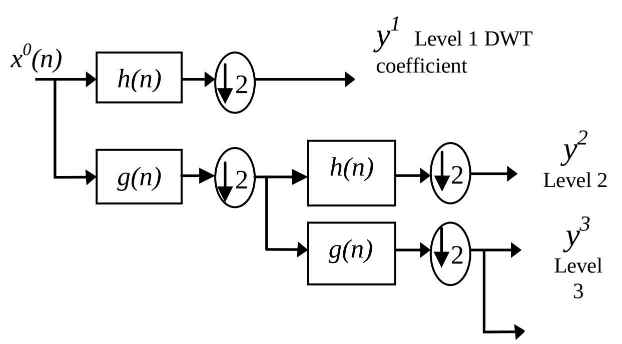

Fig.1. Filter bank representation of DWT decomposition.

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:

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

and

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

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 filter, 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 coefficient are detail coefficients of any decomposed signal.

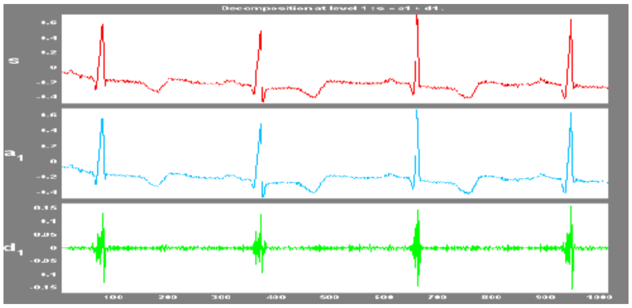

Fig.2. DWT decomposition of ECG signal.

In Fig. 2, an ECG signal (MIT BIH ECG record 100) and its decomposed result are shown. In this figure, a_1 are approximation coefficients and d_1 are detail coefficients represented at level-1 using Haar wavelet.

3. Methodology

The ECG compression is achieved using wavelet transformation and its process is based on uniform quantization and entropy encoding. The methodology of ECG compression is shown in Fig.3.

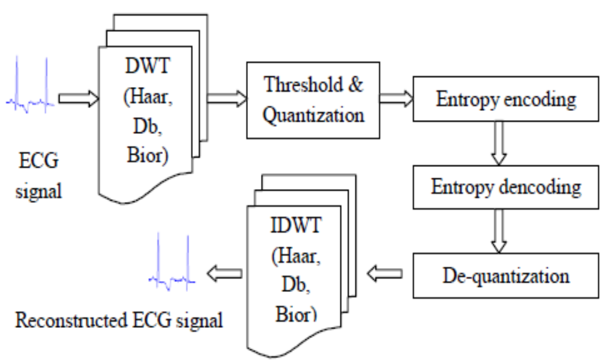

Fig.3. Compression methodology for ECG signals.

The algorithm of ECG compression is performing in three stages: (i) DWT decomposition, (ii) Threshold & Quantization, (iii) Entropy encoding. After DWT decomposition of ECG signal, its wavelet coefficients are selected on the basis of energy packing efficiency of each subband. Then apply a threshold condition (level or global), which make a fixed percentage of wavelet coefficients equal to zero [15]. Further, uniform quantizer is appeared on these coefficients. The actual compression is achieved at this stage and this compression can be further achieved with the help of entropy encoding technique (Huffman) [14,15]. Finally, compressor system gives the compressed data value of ECG signal.

3.1 Thresholding

After decomposition of an ECG signal, a thresholding is applied to the wavelet coefficients of each level from 1to N. Due to that, many of the wavelet coefficients are zero or near to zero. By applying a thresholding (level or global), the coefficient below the level is zero, which produces a many consecutive zero's which can be stored in much less space and transmission speed is high, and in the case of Global thresholding, the threshold value is set manually, this value is chosen from wavelet coefficient $(0\ldots x_{max}^{j})$ where x_{max}^{j} is maximum coefficient in the decomposition. Detailed discussion on thresholding is given in [12-15].

3.2 Quantization

After thresholding, data are uniform quantized and aim of this step quantization is to decreases the information which found in the wavelet coefficients in such a way so no error is formed. The wavelet coefficients are quantized using uniform Quantization, the computation of step size depends on three parameters [13, 14]:

(i) Maximum value, M_{max} in the signal matrix
(ii) Minimum value, M_{min} in the signal matrix
(iii) Number of quantization level, L

Once these parameters are found than step size

$$\Delta = \left(M_{\max} - M_{\min}\right)/L \tag{3}$$

Than 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 step is done, then quantization values are fed to the next stage of compression. Three parameter define above are stored in the file because these are required for creating the quantization table during reconstruction step. Detailed discussion on quantization is available in [13-15] and the reference there in.

3.3 Huffman Encoding

The quantized data contains same redundant data, means repeated data presents, it is waste of space. The way to overcoming this type problem is Huffman encoding. In Huffman encoding, the probabilities of occurrence of the symbols in the signal are computed. These symbols indices in the quantization table, these symbols arranged according to the probabilities of occurrence in descending order and build a binary tree and codeword table [13, 14].

3.4 Performance Measure Parameters

The following parameters are explained to illustrate the achieved compression and accuracy of reconstructed ECG signal after compression [13-15].

Compression ratio (*CR*):

$$\mathrm{CR} = \frac{\text{Number of significant wavelet coefficients}}{\text{Total number of wavelet coefficients}} \tag{4}$$

Signal to noise ratio (*SNR*):

$$SNR = 10\log_{10}\frac{\sigma_x^2}{\sigma_e^2} \tag{5}$$

where, σ_x^2 is mean square of speech signal and σ_e^2 is the mean square difference between the original and reconstructed signal.

Peak signal to noise ratio (*PSNR*):

$$PSNR = 10\log_{10}\frac{NX^2}{\left\| X - X'^2 \right\|} \tag{6}$$

where, N is the length of the reconstructed signal, X is the maximum absolute square value of the signal x and $\|X-X'^2\|$is the energy of the difference between the original and reconstructed signal respectively.

Normal root mean square error (*NRMSE*)

NRMSE represent the error or distortion in the reconstruction of compressed data. It is defined as

$$NRMSE = \sqrt{\frac{\left(x(n)-r(n)\right)^2}{\left(x(n)-\mu(n)\right)^2}} \tag{7}$$

where, $x(n)$ is original signal, $r(n)$ is reconstructed signal and $\mu(n)$ mean of original signal. All above mentioned parameters are exploited to measure the performance of ECG data compression.

4. Result and Discussion

In this paper, ECG signal compression is achieved based on DWT decomposition using thresholding and uniform quantization with Huffman coding. Here, performance is measured in term of CR, SNR, PSNR and NRMSE. The simulation results are obtained using Haar, db5, db7, db10 and bior3.5 wavelets at 1 to 5 decomposition levels with ECG signal samples (MIT BIH ECG record 100) are listed in Table I and shown in Fig. 5 and 6.

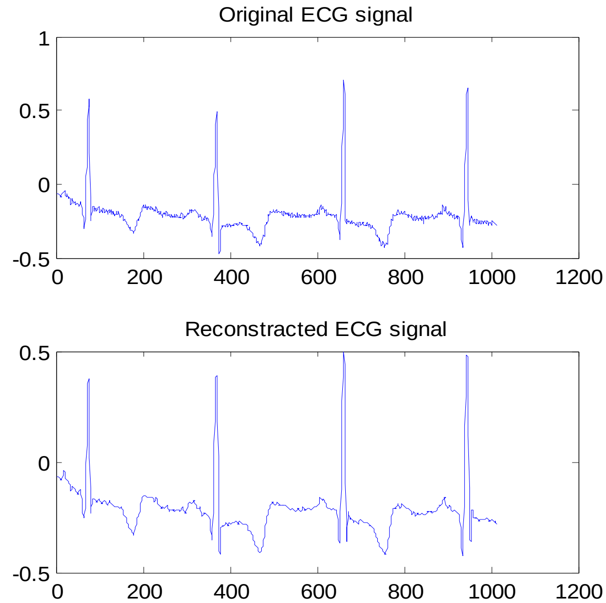

Fig. 4. Original ECG signal (MIT BIH ECG record 100) and Reconstructed ECG signal

It is evident from Table I that Haar wavelet gives high compression ratio as compare to Debauches wavelet and B-spline wavelet. While Debauches wavelet is more superior to other wavelets in term of preserving clinical information with good compression ratio also.

Figures 5 and 6 illustrate the comparative analysis of different wavelet functions with both types of thresholding (level thresholding and global thresholding). It is evident from comparative analysis of different wavelet filters that wavelet is powerful tool for analysis of ECG signal. A good compression ratio can be achieved with these wavelet filters with losing clinical information. As compared to Debauches wavelet and B-spline wavelet, Haar wavelet gives good compression ratio.

5. Conclusion

In this paper, a comparative study of performance of different wavelet for ECG compression is made. DWT decomposition is perfect to preserve clinical information at high compression ratio of ECG signal. The simulation results are shown the minimum reconstruction error in compressed signal and analysis show the uniform quantization and entropy encoder using DWT based compression is high compression ratio and high quality reconstructed signal.

TABLE I

Comparison of performance different wavelet functions

Type of Wavelet	LEVEL THRESHOLDING				GLOBAL THRESHOLDING			
	CR	***SNR***	***PSNR***	***NRMSE***	***CR***	***SNR***	***PSNR***	***NRMSE***
Haar	4.79	17.78	27.99	0.1280	7.88	12.15	25.18	0.2447
db5	4.53	14.93	26.57	0.1776	7.53	12.42	25.32	0.2373
db7	4.46	14.37	26.29	0.1894	7.21	13.09	25.65	0.2196
db10	4.25	14.82	26.52	0.1800	7.11	11.08	24.65	0.2768
bior3.5	4.49	12.45	25.33	0.2365	7.47	9.73	23.97	0.3234

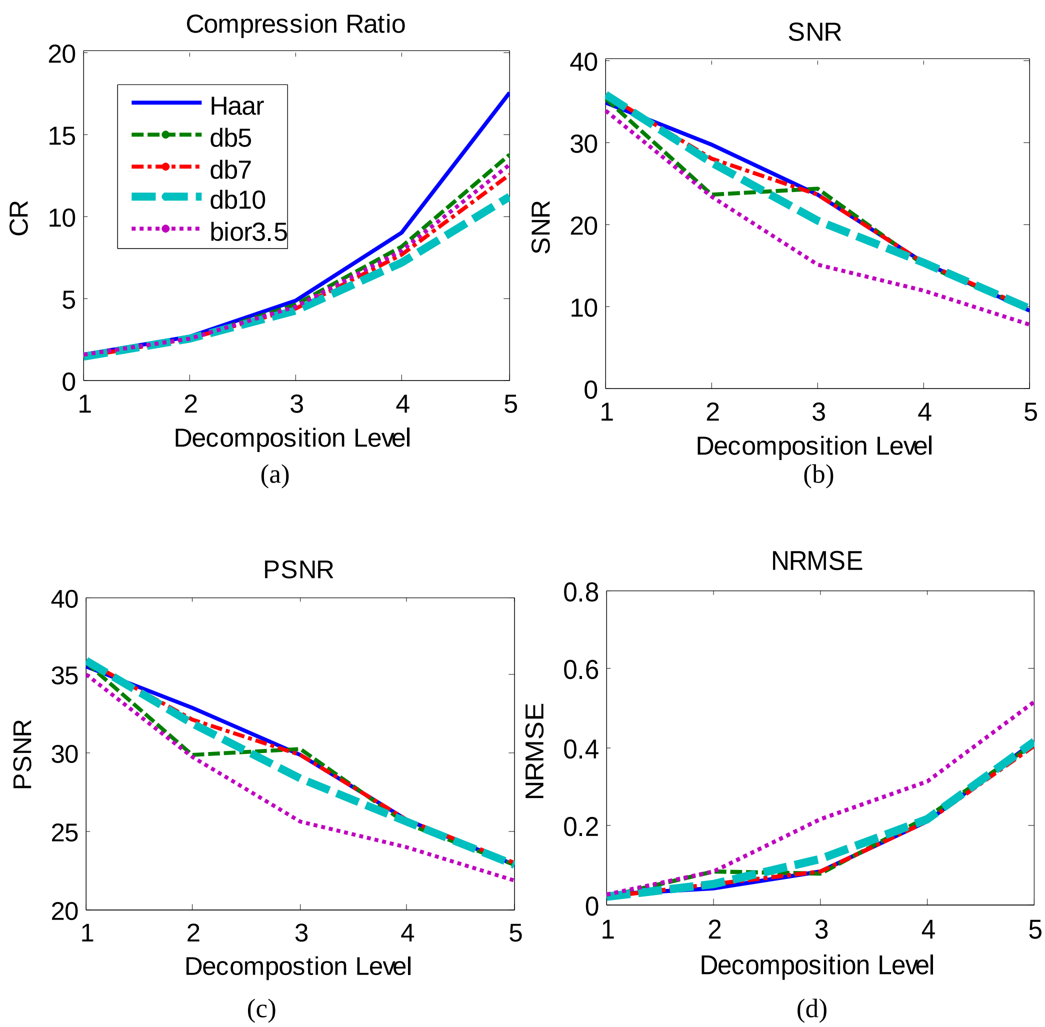

Fig. 5. Variation of performance measuring parameters of different wavelet filters with different decomposition level in case of level thresholding. (a) Compression ratio (b) *SNR* (c) *PSNR* (d) *NRMSE*.

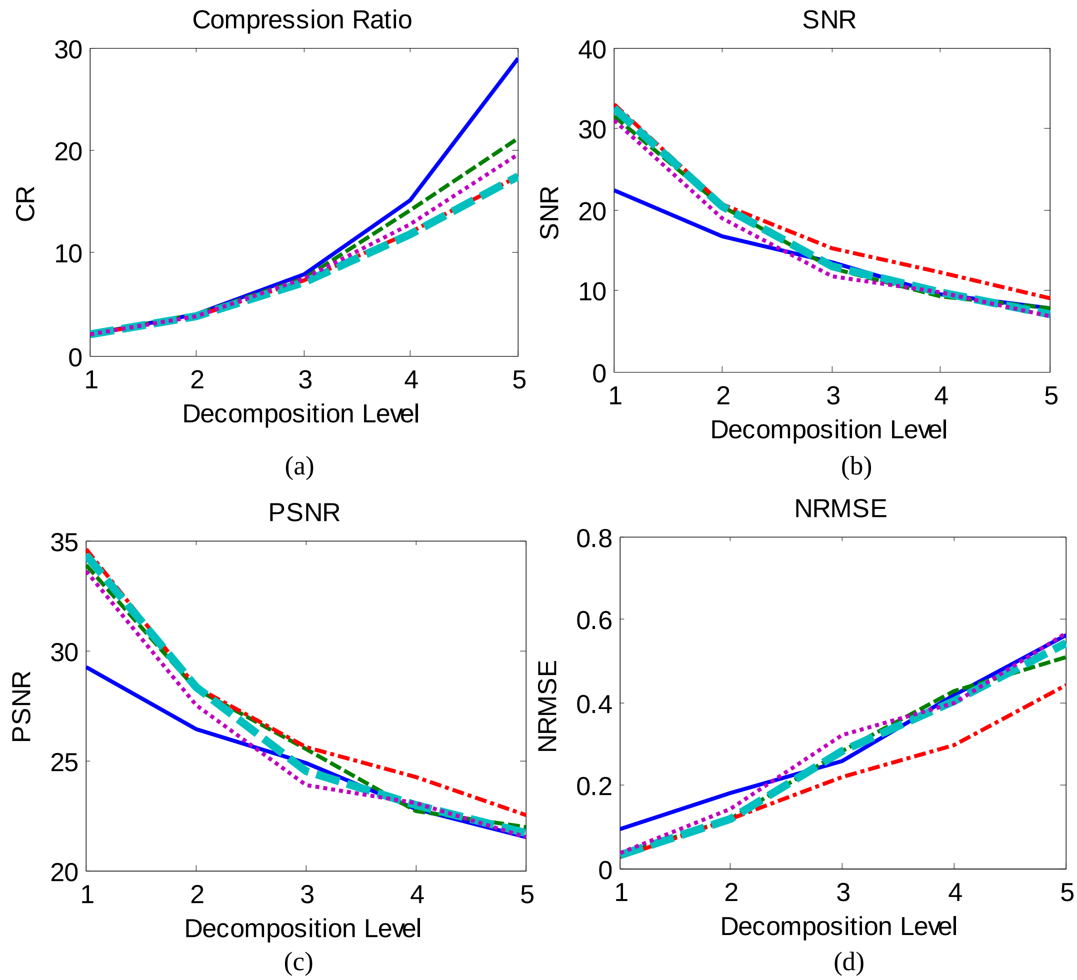

Fig. 6. Variation of performance measuring parameters of different wavelet filters with different decomposition level in case of global thresholding. (a) Compression ratio (b) *SNR* (c) *PSNR* (d) *NRMSE*

6. References

[1] R. J. Martis, C. Chakraborty and A. K. Ray, "An integrated ECG feature extraction scheme using PCA and wavelet transform", *Proceedings of IEEE India Council Conference* (INDICON 2009), 2009, pp. 88-93.

[2] R.V.S. Sastry and K. Rajgopal, "ECG Compression using Wavelet Transform", *Proceedings RC IEEE-EMBS*, BMESI , Vol-14, 1995, pp 499-500.

[3] K. Nguyen-Phi and H. Weinrichter, "ECG signal coding using wavelet transform and binary arithmetic coder", *International Conference on Information, Communications and Signal Processing* ICICS '97, Singapore, 9-12 September 1997, pp 1344-1348.

[4] S.G. Mallat, "A Theory for Multiresolution Signal Decomposition: The Wavelet Representation", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, July 1989, Vol.11, No.7.

[5] M. Nielsen, E. N. Kamavuako, M. M.Andersen, M-F. L. Lucas and D. Farina, "Optimal wavelets for biomedical signal compression", *Med Bio Eng Compute*, , 2006, Vol-44, pp 561-568.

[6] H. Khorrami and M. Moavenian, "A comparative study of DWT, CWT and DCT transformations in ECG arrhythmias classification", *Expert Systems with Applications*, August 2010, Vol-37, No. 8, pp 5751-5757.

[7] M.S. Manikandan and S. Dandapat, "Wavelet threshold based TDL and TDR algorithms for real-time ECG signal compression", *Biomedical Signal Processing and Control*, , January 2008, Vol. 3, No. 1, pp 44-66.

[8] K-Ch. Hunga, Ch-F.Tsaia, Ch-T. Ku and Hu-Sh. Wanga, "A linear quality control design for high efficient wavelet-based ECG data compression", *Computer methods and programs in biomedicine*, 2009, Vol-9 4, pp 109–117.

[9] C. Saritha, V. Sukanya and Y. N. Murthy, "ECG Signal Analysis Using Wavelet Transforms", *Bulg. J. Physics*, , 2008, Vol-35, pp 68–77.

[10] S.M. Ahmed, A.Al-Shrouf and M. Abo-Zahhad, "ECG data compression using optimal non-orthogonal wavelet transform", *Medical Engineering & Physics*, January 2000, Vol-22, Issue 1, pp 39-46.

[11] B. A. Rajoub, "An Efficient Coding Algorithm for the Compression of ECG Signals Using the Wavelet Transform", *IEEE Transaction on biomedical engineering*, April 2002, Vol. 49, No. 4.

[12] M. Blanco-Velascoa, F.Cruz-Rold´ana, J. Ignacio G-Lrenteb, J Blanco-Velascoa, C.Armiens-Aparicioa and F. Lopez-Ferrerasa, “On the use of PRD and CR parameters for ECG compression”, *Medical Engineering & Physics*, November 2005, Vol-27, Issue 9, pp 798-802.

[13] M. S. Manikandan and S. Dandapat, “Wavelet threshold based ECG compression using USZZQ and Huffman coding of DSM”, *Biomedical Signal Processing and Control*, October 2006, Vol-1, Issue 4, pp 261-270.

[14] J.Chen, F. Wang, Y. Zhang and X. Shi, “ECG compression using uniform scalar dead-zone quantization and conditional entropy coding”, *Medical Engineering & Physics*, May 2008, Vol-30, Issue 4, pp 523-530.

[15] G. Tohumoglu and K. E. Sezgin, “ECG signal compression by multi-iteration EZW coding for different wavelets and thresholds”, *Computers in Biology and Medicine*, 2007, Vol- 37, Issue 2, pp 173 – 182.