Analysis and Compression of ECG Signal using Wavelet Packet

Santosh Kumar Dubey[1] Omprakash Yadav[2]
[1,2]Department of Electronics & Telecommunication Engineering
[1,2]Chhatrapati Shivaji Institute of Technology, Durg (C.G.) Durg (C.G.), India

Abstract— Electrocardiogram (ECG) signal compression is playing a vital role in biomedical applications. The signal compression is meant for detection and removing the redundant information from the ECG signal. This paper proposes a new technique of ECG compression using Wavelet packet transform methods up to 4th level of decomposition. The quality measurement of the reconstructed signal in an electrocardiogram (ECG) compression scheme must be obtained by objective means being the compression ratio (CR), percentage root-mean-square difference (PRD), correlation coefficient (CC) and peak signal to noise ratio (PSNR) are widely used.

Key words: ECG Signals, Wavelet Packet, Peak Signal to Noise Ratio, Percent Root Difference, Compression Ratio and Correlation Coefficient

I. Introduction

According to the World Health Organization (WHO) cardiovascular diseases (CVDs) are the leading causes of death and disability in the world. An estimated 17.3 million people died from CVDs in 2004, representing 29% of all global deaths (Nadia Khaled, Sept 2011). Furthermore, in 2010, heart related diseases cost the healthcare industry in the United States $316.4 billion. This total includes the cost of health care services, medications, and lost productivity. ECG provides representation of the electrical activity of the heart over time and is probably the single-most useful indicator of cardiac function (Goras1, January, 2010). ECG signal is non-invasive and non-stationary in nature recorded by placing electrode on different locations on body surface. ECG consists of P, QRS complex, T & U waves. P wave is generated due to electrical potential generated by atrial depolarization. The propagation of the SA action potential through atria results in contraction of the atria. The magnitude of P wave is normally low (50-100μv) and 100 msec.

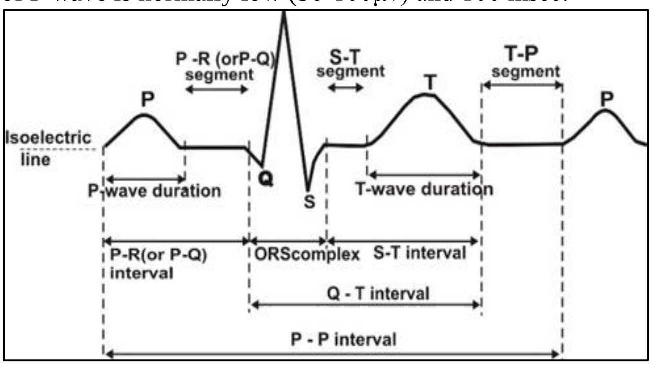

Fig. 1: Normal ECG Cycle

QRS Complex is generated when the ventricles depolarize before contraction or when the depolarization wave spreads through the ventricle. Therefore, both the P wave and components of QRS complex are depolarization wave. Q - Wave is initial negative deflection resulting from ventricular depolarization. R- Wave is first positive deflection resulting from ventricular depolarization. S -Wave is first negative deflection of the ventricular Depolarization that follows the first positive deflection. Figure 1 shows various components of a normal ECG wave.

Since ECG waves consume large bandwidth and memory, so there is a need to effectively compress these signals. ECG signals originating from heart muscles generate massive volume of digital data. They need to be compressed or approximated for efficient transmission and storage. ECG signal compression is traditionally performed in three ways: direct, transform and parameter extraction. In transformation, original ECG signals are first transformed to another domain, and then the coefficients obtained are utilized for compression. Now, a day's wavelets are gaining popularity in the field of ECG compression. Alexander Singh Alvarado et al. in 2012 have used time based encodings of the ECG recordings to perform the classification of normal heartbeats and irregular heartbeats known as arrhythmias. In terms of compression, they have reduced the sample rates for certain patients. The evaluation of classifier performance is reported in MIT-BIH arrhythmia database and in accordance with the Association for the Advancement of Medical Instrumentation (AAMI) standard [*1*]. Thresholding-Based DWT Compression Algorithm & CS-Based Compression Algorithm was used by Hossein Mamaghanian et al. in 2011. They found nonadaptive CS-based compression to exhibit inferior compression performance compared to its signal-adaptive DWT based counterpart for a given reconstructed signal quality (Hossein Mamaghanian, Sept 2011). Cheng-Tung Ku et al. introduced the 1-D reversible round-off no recursive discrete periodic wavelet transform is applied to overcome the word-length-growth (WLG) magnification effect in terms of the mechanisms of error propagation resistance and significant normalization of octave coefficients. The linear prediction model also provides a quality-guaranteed ECG data compression system with highly efficient error control. By using the MIT-BIH arrhythmia database (Cheng-Tung Ku, June 2010). Four bits for the quantization of the measurements were used by L. N. Sharma et al. in 2012. The compressed signal quality is evaluated quantitatively using PRD, and wavelet energy-based diagnostic distortion (WEDD) measures. Multiscale PCA in wavelet domain is used for dimension reduction of multichannel ECG signals without distorting the clinical information. Using dataset from CSE multilead measurement library, multichannel compression ratio of 5.98:1 was found with PRD value 2.09% and the lowest WEDD value of 4.19%. Based on, gold standard subjective quality measure, the lowest mean opinion score error value of 5.56% was found [*2*]. Software based efficient lossless ECG compression and transmission scheme was proposed by S. K. Mukhopadhyay et al. in 2013. The proposed algorithm offers a moderate to high compression ratio (7.18) without any alteration of clinical information (PRD = 0.023%) with an excellent Quality Score (312.17) [*3*]. Modelled ECG signal using Chebyshev interpolation have used by Om Prakash

Yadav et al. in 2013. The technique was implemented on a standard ECG signal with a Chebyshev polynomial of order 100 with a maximum error less than 0.1. Segmentation of ECG signal further decreases the order of the Chebyshev polynomial and thereby the maximum absolute error. The advantage of polynomial approximation is that it requires only polynomial coefficients and it is able to approximate the original ECG signal quite efficiently [*4*]. ECG compression using multidimensional multiscale parser (MMP), which is based on multiscale recurrent pattern matching, was proposed by Eddie B. L. et al. in 2009. It is preceded by an adaptation step, which reshapes the original signal and reveals its inherent structure. The MMP algorithm is a universal lossy compression method built upon the multiscale recurrent pattern matching concept, in which two vectors with different lengths can be matched. The proposed framework was assessed by running tests with the first 216 000 samples (10min) [*5*]. An easy to use and efficient ECG signal coder that is able to obtain a low bit rate whilst maintaining the quality of the reconstructed signal has been designed by Manuel Blanco-Velasco et al. in 2004. The algorithm implemented in their work is extremely easy. It is based on thresholding and has been developed to continuously process the signal without QRS detection and heartbeat segmentation. Two signal processing tools, WP and an N-PR cosine-modulated filter bank have been compared in order to establish which of them is more suitable for ECG compression [*6*]. To evaluate the compression ratio, the original signal was represented using 12 bits and the retained coefficients using 12 bits (necessary to represent the high values of the coefficients). If number of 50 coefficients were retained, the obtained compression ratio 5. In order to compare the performances of various compression techniques would be over complete dictionaries the record number 117 and 208 consisting of the first 256 & 1024 samples respectively from the MIT-BIH arrhythmia database. The ECG signals were digitized through sampling at 360 samples/s, quantized and encoded with 11 bits [*7*].

II. METHODOLOGY

ECG signals used in this paper are normal sinus data taken from MIT-BIH database. Each signal is sampled at 720 Hz frequency and is of 10 seconds.

A. *Wavelet Transform*

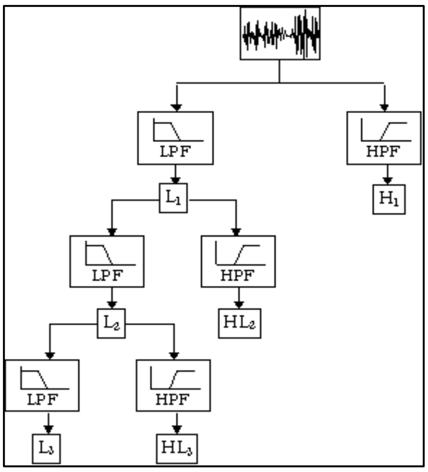

Fig. 2: Wavelet Decomposition

Wavelet analysis is a multiresolution analysis as developed by Malat (1989). The wavelet transform analyzes signals in both time and frequency domains [*8*], whereas other classical methods like Fourier transform are analyzed in frequency only. ECG signal is time-varying non-stationary and thus it is an important tool for analysis of ECG signals. In the orthogonal wavelet decomposition procedure, the generic step splits the approximation coefficients into two parts. After splitting we obtain a vector of approximation coefficients and a vector of detail coefficients, both at a coarser scale. The information lost between two successive approximations is captured in the detail coefficients. Then the next step consists of splitting the new approximation coefficient vector; successive details are never reanalyzed. Figure 2 shows Wavelet Decomposition transform.

B. *Wavelet Packet Transform*

In the wavelet packet situation, each detail coefficient vector is also decomposed into two parts using the same approach as in approximation vector splitting. This offers the richest analysis: the complete binary tree is produced as shown in the following figure. Wavelet packet transform (WPT) is an efficient tool for signal processing. Figure 3 shows Wavelet Packet Decomposition transform.

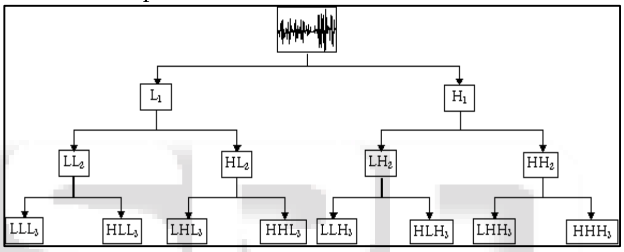

Fig. 3: Wavelet Packet Decomposition

WPT has special capabilities to achieve higher separation by analyzing the higher frequency domains of a signal. So the WPT is more suitable than wavelet in signal processing. WPT uses a pair of low pass and high pass filters to split a low-frequency and a high frequency component. So the WPT allows better frequency localization of signals.

III. ECG DATABASE AND PERFORMANCE PARAMETERS

We have taken normal sinus data from MIT-BIH data base and downloaded different ECG signals of standard data format. The performance of the compression is evaluated as:

A. *Compression Ratio (CR)*

The CR is calculated as the number of bits in the original ECG signal divided by the total number of bits in the compressed data [*9*]. It is given by:-

CR = compressed signal/original signal

B. *Percentage Mean Root Square (PRD)*

Percentage Mean Square Difference is a measure of error loss. The quality of the reconstructed signal (without sending the difference signal) is evaluated by PRD [*10*]. It is given by

$$\mathrm{PRD} = \left(\frac{\text{Reconstructed noise energy}}{\text{Original signal energy}}\right)^{\frac{1}{2}} \times 100\%$$

C. *Peak signal to noise ratio (PSNR)*

PSNR is used to measure the quality of reconstruction of lossy and lossless compression. The signal in this case is the original data, and the noise is the error introduced by compression.

$$PSNR = 10.\log_{10}\left(\frac{MAX^2}{MSE}\right)$$

D. Signal to Noise Ratio (SNR)

SNR is an engineering term for the power ratio between a signal and noise. It is expressed in terms of the logarithmic decibel scale [*11*]. It is given as:-

$$\text{SNR} = 10\log_{10}\left(\frac{\text{E}_{\text{signal}}}{\text{E}_{\text{noise}}}\right)^2$$

$$\text{SNR} = 20\log_{10}\left(\frac{\text{E}_{\text{signal}}}{\text{E}_{\text{noise}}}\right)$$

Where $\text{E}_{\text{signal:}}$ Root mean square amplitude of the signal

And $\text{E}_{\text{noise:}}$ Root mean square amplitude of the noise

E. Correlation Coefficient

The CC is employed to evaluate the similarity between the original signal and its reproduced version [*12*], defined as

$$r = \frac{n\sum xy-(\sum x)(\sum y)}{\sqrt{n(\sum x^2)-(\sum x)^2}\ \sqrt{n(\sum y^2)-(\sum y)^2}}$$

The value of r is such that -1 < r < +1. The + and – signs are used for positive linear correlations and negative linear correlations, respectively.

IV. Result and Discussion

A comparative study of performance of different wavelet and wavelet packet for ECG compression is made. DWT decomposition is perfect to preserve clinical information, while other transform method gives the distortion between original signal and reconstructed signal is measured by PRD as PRD measure is very sensitive to the DC level of the original signal. Finally, PRD and SNR are calculated to verify the improvement of the reconstructed signal. We have taken different ECG signals from MIT-BIH database. A wavelet is selected for compression. In this paper, we have decomposed the signal to fourth level. We have entropy is fixed to Shannon. Balanced sparicity normalization global thresholding is utilized to compress the ECG signals. The results obtained are shown in table 1 & 2.

S. No.	WP	CR (%)	CC	SNR	PSNR	PRD (%)
1.	Haar	93.75	0.9591	4.941	66.02	28.3
2.	Db2	98.44	0.9844	6.777	71.17	17.6
3.	Db4	98.45	0.9938	6.773	71.18	18.7
4.	Db6	98.49	0.9942	6.765	72.10	18.9
5.	Coif	98.45	0.9737	5.324	73.21	22.8
6.	Sym	98.44	0.9695	5.093	71.09	24.5
7.	Bior	98.44	0.9591	4.925	66.02	28.3

Table 1: Different parameter of ECG Signal

S. No.	WP	CR (%)	CC	SNR	PSNR	PRD (%)
1.	Haar	96.88	0.8775	5.452	72.29	47.9
2.	Db2	98.44	0.9924	5.002	72.39	44.0
3.	Db4	98.49	0.9927	5.313	73.25	45.6
4.	Db6	98.47	0.9926	5.315	73.26	46.9
5.	Coif	90.45	0.8831	5.319	77.11	45.8
6.	Sym	98.44	0.8862	5.248	74.33	45.7
7.	Bior	98.44	0.8775	5.452	72.39	47.9

Table 2: Different parameter of ECG Signal

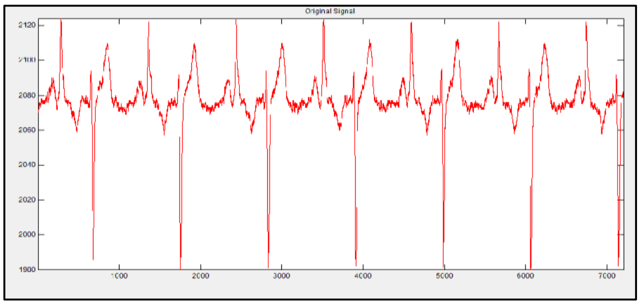

Fig. 4: Origonal signal

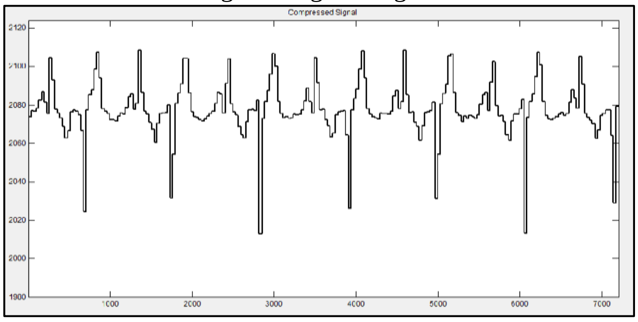

Fig. 5: Compressed signal

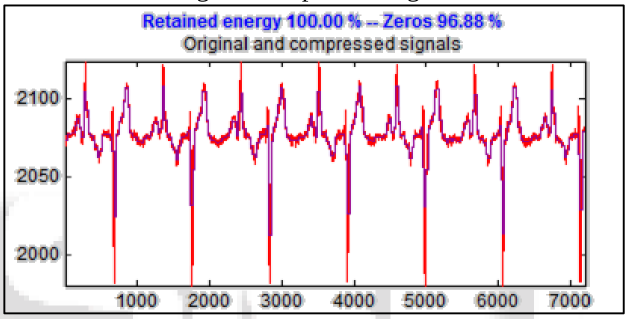

Fig. 6: Original and Compressed ECG signal

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. Figure1, Figure2, Figure3 shows the original signal, compressed signal and original & compressed signal in form of retained energy and number of zeros respectively. In figure 3 original signals shown by red color whereas compressed signal shown by blue color. The two highest compression ratios obtained are: 98.44 for Db and others and 96.88 for Haar wavelet families. The WP 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. All wavelet families and the two to six order Daubechies wavelet function is used. The result obtained in this paper indicated only minor difference in CR, CC & SNR values for each family's. Overall, the result for Daubechies family is very good when comparing all the parameters.

References

[1] Choudur Lakshminarayan, and Jose C. Prıncipe Alexander Singh Alvarado, "Time-Based Compression and Classification of Heartbeats," in IEEE, vol. 59, JUNE 2012.

[2] S. Dandapat, Member, IEEE, and Anil Mahanta, Member, IEEE L. N. Sharma, "“Multichannel ECG Data

Compression Based on Multiscale Principal Component Analysis", vol. 16, no. 4, July2012.," IEEE Transactions on Biomed. Engg., vol. 16, no. 4, July 2012.
[3] S. Ghosh, S. Chakraborty, S.Das S. K. Mukhopadhyay, "Lossless ECG Compression Technique and GSM Based Tele-Cardiology Application," International Journal on Smart Sensing and Intelligent System, 2013.
[4] Shashwati Ray Om Prakash Yadav, "Modeling And Segmentation Of Ecg Signals Through Chebyshev Polynomials," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, no. 10, pp. 4696-4703, OCTOBER 2013.
[5] M Nuno. M. Rodrigues, Member, IEEE Eddie B. L. Filho, "On ECG Signal Compression With 1-D Multiscale Recurrent Patterns Allied to Preprocessing Techniques," in IEEE Transactions On Biomedical Engineering, vol. 56, MARCH 2009, pp. 896-900.
[6] Fernando Cruz-Rold Manuel Blanco-Velasco, "A low computational complexity algorithm for ECG signal compression," pp. 1-28, JULY 2004.
[7] Monica Fira and Liviu Goras, "Biomedical Signal Compression based on Basis Pursuit," International Journal of Advanced Science and Technology, vol. 14, January 2010.
[8] Dong Youn Kim, William A. Pearlman Zhitao Lu, "Wavelet Compression of ECG Signals by the Set Partitioning in Hierarchical Trees (SPIHT) Algorithm," IEEE Transactions on Biomedical Engineering, pp. 1-15, January 2000.
[9] Gyu-Bong Lee, Kil-Houm Park Young-Bok Joo, "2-D ECG Compression Using Optimal Sorting and Mean Normalization," in International Conference on Machine Learning and Computing, vol. 3, Singapore, 2011, pp. 472-476.
[10] Amine Naït-Ali, "A New Technique for Progressive ECG Transmission using Discrete Radon Transform," World Academy of Science, Engineering and Technology, pp. 761-766, 2008.
[11] Syed Naseem Ahmad Ruqaiya Khanam, "ECG Signal Compression for Diverse Transforms," IISTE, vol. 2, no. 5, pp. 1-9, 2012.
[12] Member, IEEE, and Shuichi Itoh, Member, IEEE Jie Chen, "A Wavelet Transform-Based ECG Compression Method Guaranteeing Desired Signal Quality," IEEE Transactions On Biomedical Engineering, vol. 45, no. 12, pp. 1414-1419, December 1998.
[13] Member, IEEE, David Atienza, Member, IEEE Nadia Khaled, "Compressed Sensing for Real-Time Energy-Efficient ECG Compression on Wireless Body Sensor Nodes," IEEE Transactions On Biomedical Engineering, vol. 58, no. 9, pp. 2456-2465, Sept 2011.
[14] V. S. Chouha and H. P. Sinha Rekha Rani, "Automated Detection of QRS Complex in ECG Signal using Wavelet Transform," IJCSNS International Journal of Computer Science and Network Security, vol. 15, no. 1, pp. 1-5, January 2015.
[15] Choudur Lakshminarayan, and Jose C. Prıncipe Alexander Singh Alvarado, "Time-Based Copmression and Classification of Heartbeats," IEEE Transaction on Biomedical Engg., vol. 59, June 2012.
[16] Student membet IEEE,Nadia khaled, member IEEE,David Atienza, member IEEE Hossein Mamaghanian, "“Compressed Sensing for Real-Time Energy-Efficient ECG Compression on Wireless Body Sensor Nodes," IEEE Transaction on Biomedical Engg., vol. 58, no. 9, Sept 2011.
[17] Member, IEEE, King-Chu Hung, Member, IEEE, Tsung-Ching Wu, Member, IEEE, And Huan-Sheng Wang, Member, IEEE Cheng-Tung Ku∗, "Cheng-Tung Ku∗, Member, IEEE, King-Chu Hung, Member, IEEE, Wavelet-Based ECG Data Compression System With Linear Quality Control Scheme ," IEEE Transactions on Biomed. Engg., vol. 57, no. 6, June 2010.