

Performance Evaluation of Percent Root Mean Square Difference for ECG Signals Compression

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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. Wavelet transform methods are very powerful tools for signal and image compression and decompression. This paper deals with the comparative study of ECG signal compression using preprocessing and without preprocessing approach on the ECG data. The performance and efficiency results are presented in terms of percent root mean square difference (PRD). Finally, the new PRD technique has been proposed for performance measurement and compared with the existing PRD technique; which has shown that proposed new PRD technique achieved minimum value of PRD with improved results.

Keywords: ECG compression, thresholding, wavelet coding.

1. INTRODUCTION

Wavelets are useful tools for data compression and have been applied for numerous problems such as ECG, pattern recognition and the ECG detection characteristics points. ECG signal is a very attractive source of information for physicians in diagnosing heart diseases [1]. Nowadays, ECG compression is being used tremendously because of the data reduction of ECG signal in all aspects of electrocardiography and considers an efficient method for storing and retrieving data. Normally, 24-hour recordings of ECG signals are desirable to detect and monitor heart abnormalities or disorders. Therefore the ECG data in digital form becomes one of the important issues in the biomedical signal processing community [2,3].

ECG compression is a well-established and potential area of research with numerous applications such as diagnosis, taking care of patients and signal transfer through communication lines. Wavelet transform is a powerful and efficient technique in signal processing for compressing ECG signals [4].

Many studies have done on the PRD calculation using the different denominators such as mean, without mean and baseline 1024. However no information is available on the PRD calculation using the approach of median as a denominator. The main objective of this paper is to compare the result of PRD with preprocessing and without preprocessing of ECG data and proposed new PRD technique with median.

2. ECG SIGNAL COMPRESSION ALGORITHMS

The main concern of the compression is the removal of redundant and irrelevant information from the ECG signal. There are many compression algorithms that have been presented and these algorithms are based on Wavelet transform.

3. WAVELET TRANSFORM

The wavelet transform or wavelet analysis is the most recent solution to overcome the shortcomings of the Fourier transform. Wavelet analysis is a form of “multi-resolution analysis”, which means those wavelets are better suited to represent functions which are localized both in time and frequency. This fact makes Wavelets useful for signal processing where knowledge of frequencies and the location of wavelets are essential for in time information.

Wavelet Functions are generated from one single function by scaling and translation

$$(1)$$

Where a is the dilation and b is the location parameter of the wavelet.

The basic idea of wavelet transform is to represent any function f as the linear superposition of wavelet [1]. Discrete coefficients describing the scaling and translations are called wavelet coefficients. The wavelet transform can be implemented by subband coding for perfect reconstruction of the signals. The decomposition of signal with the pair of low-pass and high-pass filter those are suitable designed to form quadrature mirror filters (QMFs). The output of each analysis filter is downsampled by a factor of two. The inverse transform is obtained by selecting the highest layer, where the wavelet coefficients are upsampled by a factor of two and then filtered with the synthesis QMF pair. The low-pass and high-pass outputs of the synthesis filters are combined to get the low-pass signal for the next lower level [9].

A brief description on each method along with relevant literature information (other research's work) is discussed below.

Hilton [5] has presented wavelet and wavelet packet method. This approach was based on embedded zero wavelet (EZW) coding to get the best-reconstructed signal for a given rate under the constraints that the encoding is embedded. The wavelet packet bases inherit the properties of the wavelets they are built from, such as orthonormality and smoothness.

Lu et al. [6] have presented a new approach of set partitioning hierarchical tree (SPIHT) algorithm for ECG signals. The SPIHT algorithm has achieved remarkable success in image coding. The authors have modified the algorithm for the one-dimensional case for generating a bit stream progressive in quality [6].

Chen et al. [7] have suggested a new wavelet-based Vector quantization (VQ) ECG compression approach. Wavelet transform coefficients are quantised with uniform scalar dead zone quantiser. The Exp-Golomb coding is used to code the length of runs of the zero coefficients. The algorithm is quite robust to different ECG signals because no a priori signal statistic is required.

Benzid et al. [8] present a new quality-controlled, wavelet-based, compression method for ECG signals. Wavelet coefficients are thresholded iteratively for guarantee of predefined goal percent root mean square difference (GPRD) is achieved within acceptable boundary. The Quantization strategy for extracted non-zero wavelet coefficients (NZWC) is coded using 8 bit linear quantizer. Finally, the Huffman coding is used to achieve high quality of reconstructed signals.

Rajoub [9] has used Energy packing efficiency (EPE) approach for the compression of ECG signals to achieve desired clinical information. Wavelet coefficients are thresholded on the desired energy packing efficiency and significant map is compressed efficiently using the run length coding.

Alshkali and Amjed [10] commented on the EPE compression approach proposed by Rajoub. The authors have claimed that the several important points regarding accuracy, methodology and coding were found to be improperly verified during implementation. This paper discusses these findings and provides specific subjective and objective measures that could improve the interpretation of compression results in these research-type problems.

Manikandan and Dandapat [11] have presented a wavelet threshold-based method for ECG signal compression. Significant wavelet coefficients are selected based on the energy packing efficiency and quantized with uniform scalar zero zone quantizer. Significant map is created to store the indices of the significant coefficients. This map is encoded efficiently with less number of bits by applying the significant Huffman coding on the difference between the indices of the significant coefficients.

Benzid et al. [12] have applied pyramid wavelet decomposition for ECG signals using the bior4.4 wavelet up to 6th level. The resultant coefficients got through the iterative threshold until a fixed percentage of wavelet coefficients will be reached to zero. Then the loss less Huffman coding has been used to increase the compression ratio.

Manikandan and Dandapat [13] have presented a target distortion level (TDL) and target data rate, wavelet threshold-based ECG signal compression techniques. These are based on the energy packing efficiency, uniform scalar zero zone quantizer and differencing integer significance map.

Tohumoglu and Sezgin [14] have presented new approach based on EZW algorithm. The purpose of this paper to apply the modified EZW algorithm for ECG signal compression and evaluate the performance with respect to different classes of wavelets and threshold values.

4. PROPOSED METHOD

ECG signals for the experiment have been taken from MIT BIH arrhythmia database for record 117. We divided signals into frames and each frame length is 1024. At first, the ECG signal is preprocessed by normalization, mean removal and zero padding. The objective of preprocessing is to get the magnitudes of wavelet coefficients which would be less than one and is reduced reconstruction error. Preprocessing can be described by the following equation [9]:

$$(2)$$

Where y_i preprocessed signal, x is the original signal and m_x is defined as

$$(3)$$

The preprocessed and un-processed ECG signals are decomposed by using the discrete wavelet transform up to the fifth level using the different families of wavelet to obtain the wavelet coefficients (WC). A threshold method of ECG signals is applied on the discrete wavelet coefficients. Threshold method has been described by the following equation:

$$Thres-coefficients = f_{TH}(WC, C_{Number}) \quad (4)$$

Where f_{TH} is the function of designed algorithm, WC is the wavelet coefficients and C_{Number} is number of coefficients selected. The threshold mechanism will automatically select the number of coefficients based on the value of C_{Number} . The process of threshold removes the unnecessary information from the ECG signal. Now we can fix the number of threshold coefficients required during the threshold process. A binary map is used to store the significant information of the coefficients after scanning the threshold coefficients. The run length coding scheme is used to compress the significant map [9].

5. RESULTS AND DISCUSSION

To measure the performance for different compression methods, the distortion between original signal and reconstructed signal is measured by PRD. In the following, the most popular measures are presented [8]:

$$\times 100 \quad (5)$$

$$\times 100 \quad (6)$$

$$\times 100 \quad (7)$$

$$\times 100 \quad (8)$$

Where x_{ori} denotes the original signal, x_{rec} denotes the reconstructed signal and n denotes the number samples within one data frame, $mean(x_{ori})$ denotes the mean of original signal and $median(x_{ori})$ denotes median of original signal. PRD1 was used by [5,9] which depend on the dc level of the original signal. PRD2 is considered as a quality measure, it is very simple and also used to evaluate the reliability of the reconstructed signal. PRD3 can be found as an example in [10] where they used the mean of the original signal. Median is a more suitable parameter to calculate the average values of data as compared to mean.

From Table 1, it can be seen that the PRD value 0.3335% of without preprocessing (PRD1_{WO}) achieved the minimum value than PRD value 0.335% with preprocessing (PRD1_W) in BiorSpline (bior4.4). Difference between PRD1_W and PRD1_{WO} shows not much difference but shows lower values than without preprocessing in most cases. Table1 also showed that the PRD_{New} technique is achieved lower values than PRD3 values in different wavelet of families. Difference between PRD3 (mean) and PRD_{New} (median) is remarkable with all positive values. This shows the significance of median parameter in calculating PRD. Figure 1 shows the trend of PRD with respect to wavelet family for proposed method of ECG signals. From figure 1, it can be seen that PRD_{New} is achieved minimum values as compared to PRD3 values. Figure 2 and 3 show the original and reconstructed signals for the record of 117. The proposed method preserves all clinical information and also removes the noise in the original signal which is shown in figure 3.

Table 1: PRD COMPARISON RESULT OF PREPROCESSING AND NEW PRD TECHNIQUE

Wavelet Family No. Name.	PRD1 _W %	PRD1 _{WO} %	Difference between PRD1 _W & PRD1 _{WO} (%)	PRD3%	PRD _{New} %	Difference between PRD3 & PRD _{New} (%)	
1	haar	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
2	db1	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
3	db2	0.3796	0.3641	0.0002	7.3633	7.1099	0.0025
4	db3	0.3566	0.3472	0.0001	6.9185	6.6804	0.0024
5	db4	0.3563	0.348	0.0001	6.9134	6.6752	0.0024
6	db5	0.3512	0.3619	-0.0001	6.8151	6.5809	0.0023
7	db6	0.3554	0.3683	-0.0001	6.8954	6.658	0.0024
8	db7	0.3612	0.3885	-0.0003	7.0026	6.7613	0.0024
9	db8	0.3577	0.4162	-0.0006	6.9412	6.7024	0.0024
10	db9	0.3722	0.4423	-0.0007	7.2148	6.9666	0.0025
11	db10	0.3765	0.4919	-0.0012	7.2945	7.0431	0.0025
12	sym2	0.3796	0.3641	0.0002	7.3633	7.1099	0.0025
13	sym3	0.3566	0.3472	0.0001	6.9185	6.6804	0.0024
14	sym4	0.347	0.3432	0.0000	6.7343	6.5026	0.0023
15	sym5	0.3474	0.3469	0.0000	6.7406	6.509	0.0023
16	sym6	0.3431	0.3557	-0.0001	6.6584	6.4294	0.0023
17	sym7	0.3499	0.3701	-0.0002	6.787	6.5536	0.0023
18	sym8	0.3402	0.3734	-0.0003	6.6034	6.3757	0.0023

19	coif1	0.3835	0.3731	0.0001	7.4379	7.1823	0.0026
20	coif2	0.3484	0.3612	-0.0001	6.76	6.5268	0.0023
21	coif3	0.3438	0.3896	-0.0005	6.672	6.4422	0.0023
22	coif4	0.3412	0.4501	-0.0011	6.622	6.3939	0.0023
23	coif5	0.3442	0.5414	-0.0020	6.6775	6.4473	0.0023
24	bior1.1	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
25	bior1.3	0.5999	0.613	-0.0001	11.5962	11.1979	0.0040
26	bior1.5	0.5958	0.6456	-0.0005	11.5266	11.1317	0.0039
27	bior2.2	0.3465	0.3352	0.0001	6.726	6.4944	0.0023
28	bior2.4	0.3383	0.3401	0.0000	6.5656	6.3392	0.0023
29	bior2.6	0.3404	0.3599	-0.0002	6.6057	6.3778	0.0023
30	bior2.8	0.3438	0.3842	-0.0004	6.6703	6.4402	0.0023
31	bior3.1	0.4552	0.4388	0.0002	8.8384	8.5344	0.0030
Wavelet Family No. Name.	PRD1W %	PRD1WO %	Difference between PRD1W & PRD1WO (%)	PRD3%	PRDNew %	Difference between PRD3 & PRDNew (%)	
32	bior3.3	0.3712	0.37	0.0000	7.2119	6.9632	0.0025
33	bior3.5	0.3428	0.3582	-0.0002	6.6578	6.4278	0.0023
34	bior3.7	0.3398	0.3641	-0.0002	6.593	6.3656	0.0023
35	bior3.9	0.3359	0.3901	-0.0005	6.5227	6.2974	0.0023
36	bior4.4	0.335	0.3335	0.0000	6.5012	6.2771	0.0022
37	bior5.5	0.3474	0.3529	-0.0001	6.7446	6.5123	0.0023
38	bior6.8	0.3376	0.3725	-0.0003	6.5529	6.3275	0.0023
39	rbio1.1	0.5932	0.5835	0.0001	11.4709	11.078	0.0039
40	rbio1.3	0.3585	0.3445	0.0001	6.9571	6.7175	0.0024
41	rbio1.5	0.3486	0.3504	0.0000	6.7667	6.5338	0.0023
42	rbio2.2	0.5549	0.5525	0.0000	10.7275	10.359	0.0037
43	rbio2.4	0.396	0.4069	-0.0001	7.6756	7.4122	0.0026
44	rbio2.6	0.3847	0.4157	-0.0003	7.4594	7.2024	0.0026
45	rbio2.8	0.3845	0.4351	-0.0005	7.4584	7.202	0.0026
46	rbio3.1	4.8656	4.4473	0.0042	93.903	90.6597	0.0324
47	rbio3.3	0.78	0.7925	-0.0001	15.0346	14.518	0.0052
48	rbio3.5	0.517	0.574	-0.0006	9.9859	9.6431	0.0034
49	rbio3.7	0.4618	0.5549	-0.0009	8.9417	8.635	0.0031
50	rbio3.9	0.4425	0.5595	-0.0012	8.5795	8.2852	0.0029
51	rbio4.4	0.3707	0.3793	-0.0001	7.1867	6.9396	0.0025
52	rbio5.5	0.3522	0.37	-0.0002	6.8319	6.5965	0.0024
53	rbio6.8	0.3621	0.4058	-0.0004	7.0238	6.7824	0.0024
54	dmey	0.371	42.1938	-0.4182	7.1887	6.9413	0.0025

A summary of the performance results for signal compression is shown in Table 2. Table 2 gives the comparison of the proposed method with other existing methods for the record 117 on the basis of PRD and CR. From Table 2, it can be seen that the PRD value of 2.6% with CR 8:1 for the record of 117 achieved by Hilton. Using the SPIHT approach by Lu et al, it was found that the PRD value is 1.18% with CR 8:1 for the 117 record. From Table 2, it can be seen that the PRD value of 1.04% with CR 27.93:1 for the record of 117 achieved by Benzid.

Table 2: PERFORMANCE RESULTS FOR COMPRESSING RECORDS USING THE DIFFERENT METHODS

METHOD	SIGNAL	CR	PRD %
Hilton [5]	117	8:1	2.6%(PRD1)
Lu et al[6]	117	8:1	1.18%(PRD1)

Benzid [8]	117	27.93:1	1.04% (PRD1)
Rajoub [9]	117	22.19:1	1.06% (PRD1)
Manikandan [11]	117	8.5:1	0.956% (PRD1)
Benzid [12]	117	16.24:1	2.55% (PRD1)
Proposed	117	8.70:1	0.335%(PRD1 _W)

Using the energy packing efficiency approach by Rajoub, it was found that the PRD value produced 1.06% with the CR 22.19:1 for the 117 record. Table 2 also has shown that the PRD value of 0.956% with CR 8.5:1 for the record of 117 achieved by Manikandan. Using the fixed the percentage of wavelet coefficient approach by Benzid, it was found that the PRD value produced 2.55% with the CR 16.24 for the 117 record. In this investigation, it can be seen that the PRD value of PRD1_W 0.335% with CR 8.70:1 for the record of 117 achieved by our proposed method using BiorSpline(bior) wavelet family which is much lower than reported existing PRD values.

Comparison between PRD3 and PRDNew values

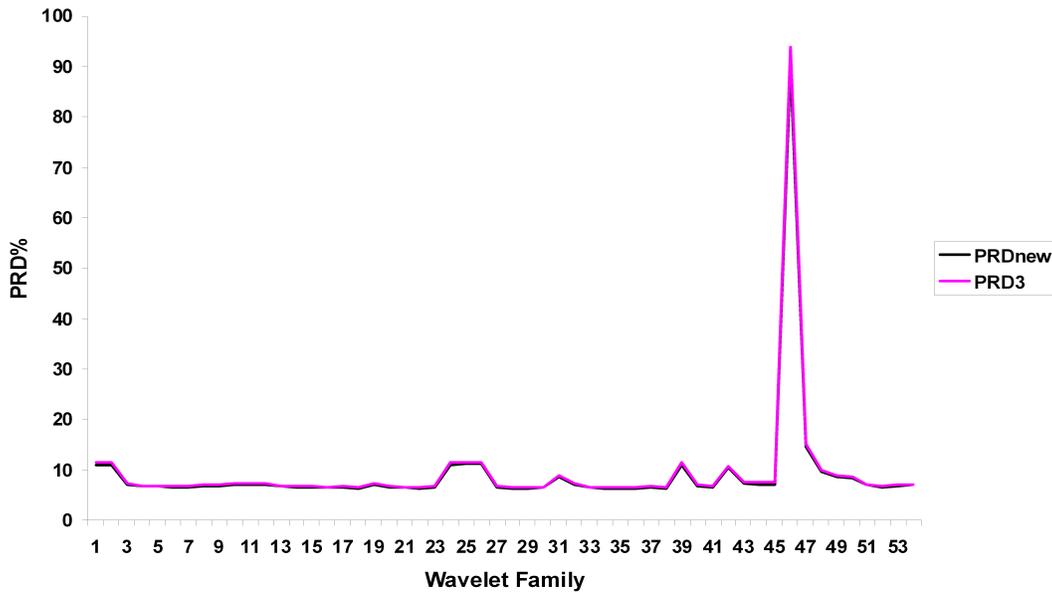


FIGURE 1: comparison of mean and median values of PRD for ECG signals

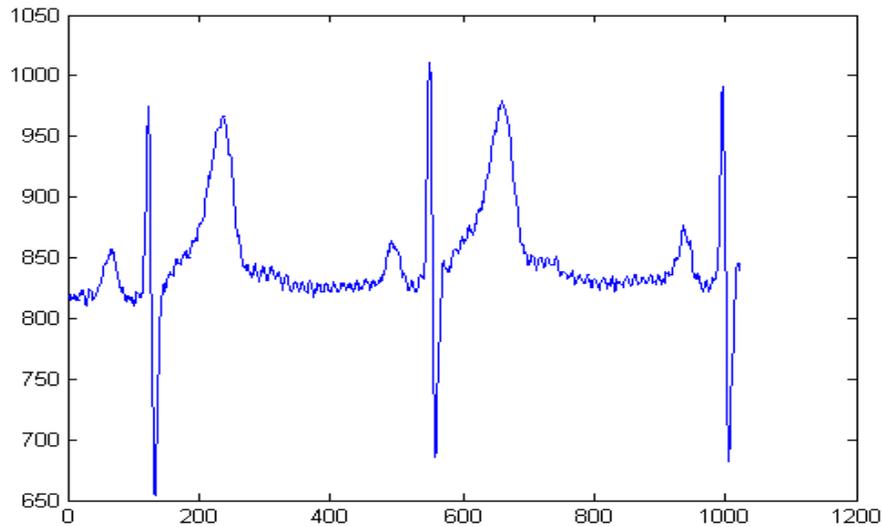


FIGURE 2: Original ECG Signals from the Record 117

6. CONSLUSION & FUTURE WORK

A new PRD technique for ECG signal is proposed in this paper. In this paper, a study of ECG signal compression using preprocessing and without preprocessing approach on the ECG data is described. The conclusions can be drawn from the study that there is no significant difference in PRD values (results) of preprocessing and without preprocessing of ECG data when use proposed method. The test results of PRD (median) technique has shown the superior performance compare to that of PRD (mean) formula for all the experimented wavelet families. Future research work on the entropy coding of the wavelet coefficients is being carried out in the research center.

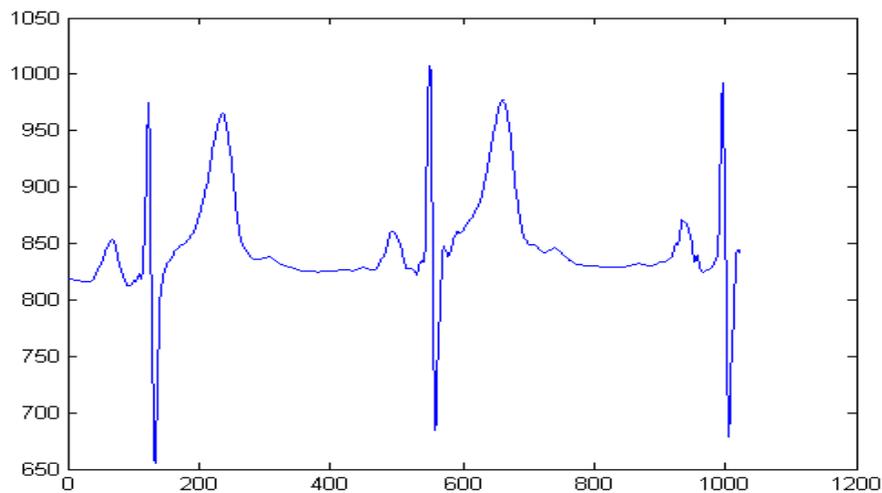


FIGURE 3: Reconstructed ECG Signals from the Record 117 without noise

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