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A Hybrid Lossy plus Lossless Compression Scheme for ECG Signal

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Abstract – *This paper present a hybrid ECG signal compression scheme, in which the whole ECG signal is segmented into two regions first ROI (Region of Interest) and second NONROI (NON Region of Interest). It uses lossy compression for NONROI which is done using DWT (Discrete Wavelet Transform) and further compressed using lossless using RLE (Running Length Encoding). The clinically important ROI part is compressed using lossless compression which uses RLE. The 48 records of MIT-BIH database are subjected to compression and Compression Ratio (CR), Signal to Noise Ratio (SNR), Percentage Root Mean Square difference (PRD), and Root Mean Square Error (RMSE) are evaluated. Average CR given by this method is 11.58 and average PRD is .896.*

Key Words*: ROI, NONROI, Lossy, Lossless, *DWT (Discrete Wavelet Transform), RLE (Running Length Encoding), Compression Ratio (CR), Percentage Root Mean Square difference (PRD), Root Mean Square Error (RMSE) , Signal to Noise Ratio (SNR).

1. INTRODUCTION

ECG signal indicates the electrical activity of the heart which displayed graphically. ECG signal is one of the most essential biomedical signals for the monitoring and diagnosis of heart diseases. The divergence in the normal electrical patterns indicates various cardiac disorders. In this way, ECG is widely used in the diagnosis and treatment of cardiac disease. The recorded ECG signals are most widely used in the applications such as, cardiac diagnosis, real-time transmission over telephone networks, monitoring, patient databases and long-term recording.

For the continuous ECG monitoring, a huge quantity of ECG data and it occupies a lot of storage space. For transmission of ECG signal over telephone channels or wireless channels a large bandwidth is required. Therefore, to save the storage and transmission band width the compression of ECG signal becomes essential. These compression techniques are basically of two types Lossless and lossy. In lossless compression techniques we are able to generate signal same as original with negligible error. Therefore, lossless method has less amount of compression. In lossy methods we do not get reconstructed signal same as original signal there is some loss of data. Various methods for ECG compression of that were used in the literature can be classified into 3 types which are the direct time-domain techniques, parameters optimization techniques and transformed frequency-domain techniques

1. Direct time-domain compression techniques: In direct time -domain compression method the compression of signal takes place directly in the time domain. The reconstruction of the signal takes place by interpolating the adjacent samples. CORTES [1], Turning Point [2], AZTEC [3], Delta coding [4] are some of the direct methods which frequently used for direct compression scheme.

2. Transform method: In this method the signal is transformed into frequency domain to compact the signal energy into a small number of transformed coefficients. For reconstruction of the signal inverse transform is taken. Walsh transforms [5], Karhunen-Loeve transforms [6], Hermite transforms [7], Fourier transforms [8], discrete cosine transform [9], wavelet transform [10] are some of the transform methods.

3. Parameter extraction method: In the parameter extraction method various features and parameter are extracted from the original signal.

All the methods used in the literature have their merits and demerits. To get the higher compression we have to compromise with some clinical information. This paper proposed a hybrid compression scheme which use lossless compression method to compress QRS complex and lossy method is used to compress rest of the ECG signal. The rest of paper is structured as follows. Section 2 gives brief description of the methodology used in the paper, section 3 gives the result and discussion, section 4 is conclusion.

2. METHODOLOGY

In the proposed method the ECG signal is first segmented to two part QRS complex (region of interest (ROI)) and rest of ECG signal (non-region of interest (NONROI). After the segmentation, lossy compression using discrete wavelet transform is subjected to NONROI part and a lossless compression of ROI part is done by Running Length Encoding (RLE). A detailed description of the proposed method is given in Fig -1 which shows compression of ECG signal and Fig -2 shows reconstruction of ECG signal.

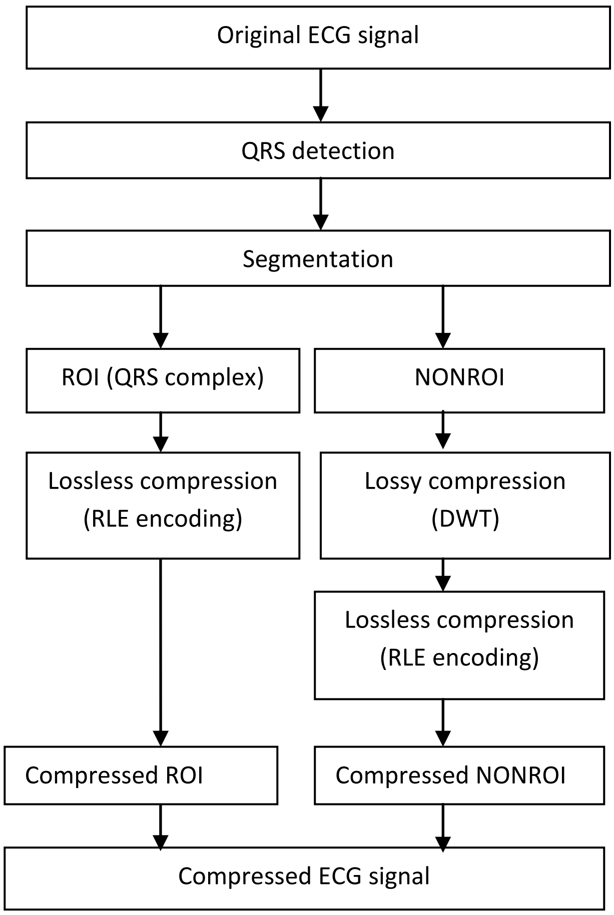


Fig-1: Compression of ECG signal

2.1 QRS detection and ECG segmentation

For detection of QRS complex various methods are used in the literature but Pan-Tompkins methods is better than rest of the method. So for detection of QRS complex Pan-Tompkins method is used [11]. This method involves 3 steps for detection of QRS complex. First step is linear digital filtering, second is nonlinear transformation followed by decision rule algorithms. In the linear processes the signal is passed through bandpass filter having a pass band of 5 Hz to 11 Hz. The bandpass filter reduces the influence of, 60 Hz interference, muscle noise, T-wave interference, and baseline wander, thus performing pre-processing.. After the band pass filtering, the QRS complex slope information is achieved by differentiating the signal. The squaring of the differentiated signal is done point by point which makes all data points positive and provides a nonlinear amplification. After this with the help of moving-window integration we can find the width of QRS complex which gives additional information to R peak slope detection. The width of the window must be same as the width the QRS complex.

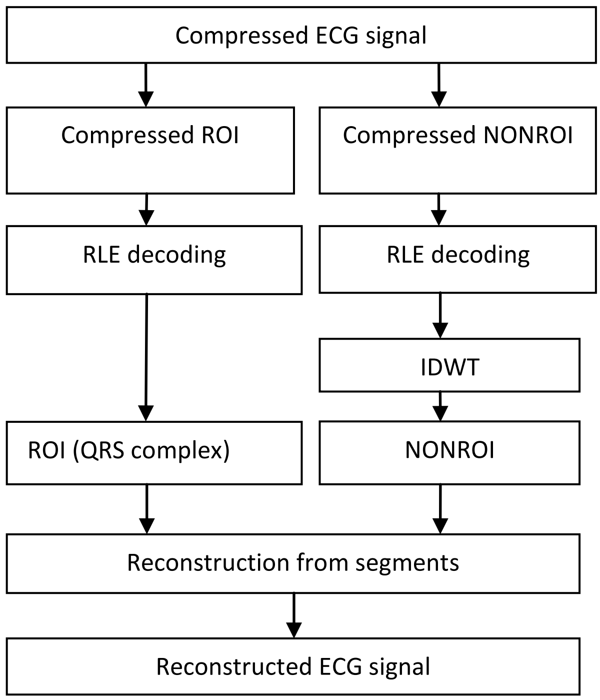
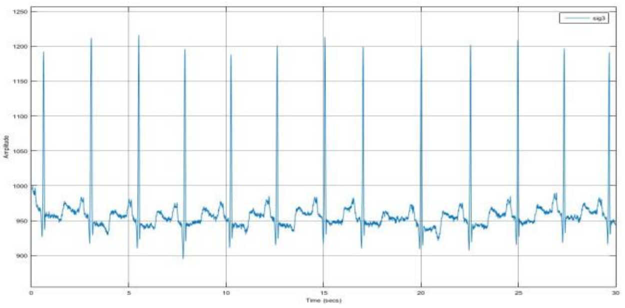


Fig- 2: Reconstruction of ECG signal

The width of the window for sample rate of 200 samples/s, window is 30 samples wide (150 ms). This algorithm uses a dual-threshold technique which is used to find missed beats. There are two different threshold levels. In which one level is half of other level. The thresholds are adaptive and adapt the characterised of the signal thus reducing the error of missed beat.

After the detection of QRS complex the segmentation of ECG signal is done. The starting point or indices of Q wave (Q_i) and ending point or indices of S wave (S_i) is stored in a counter. And the all interval between (Q_i) and (S_i) are stored in a continuous manner one by one for all i = 1,2,3,4 …n where n = number of QRS complex detected in complete samples of ECG. All the samples stored between interval (Q_i) and (S_i) gives ROI. And rest of the samples constitute NONROI part. The original ECG signal before segmentation, ROI and NONROI parts of ECG signal is shown in Fig- 3.



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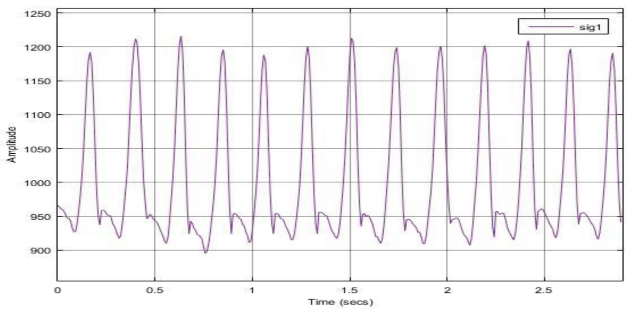

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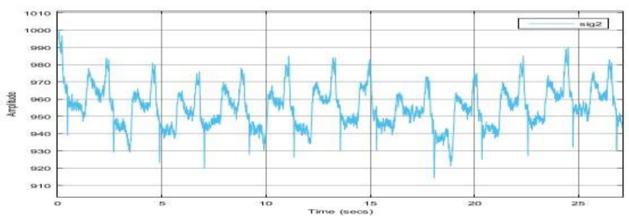


(c)

Fig- 3: (a) Original ECG signal record 100 taken from MIT-BIH. (b) Segmented ROI part (QRS complex). (c) Segmented NONROI part.

2.2 Lossy compression using Discrete Wavelet Transform

Discrete Wavelet Transform (DWT) is the digitized of the version of continuous the wavelet transform (CWT). In DWT the signal is transformed into frequency sub-bands. By doing this it becomes easy to decompose the signal into various different waveforms. The techniques based on wavelet fit with the most of signal filtering methods and various encoding schemes producing better compression results [14]. In this method using highpass *h(n)* and lowpass *g(n)* FIR filter banks the signal is decomposed into J decomposition levels which is shown in Fig. 4, and its then down-sampled by a factor of 2. The decomposed signal in each level is then divided into low frequency signal (an) and high frequency signal (d_n). The low frequency signal a_n is called the approximation signal and the high frequency signal d_n is called the detail signal. After this the low frequency signal is then decomposed again into two signals in the next level and so on up to d_J and a_J. The filter banks are constructed from wavelet basis functions such as Daubechies, Biorthogonal, Coiflet, Symmlet, Morlet, and Mexican Hat. The selection of wavelet transform function depends on the application. The decomposed signal can be reconstructed again into the original signal using reconstruction filters, which are the inverse of the decomposition filters.

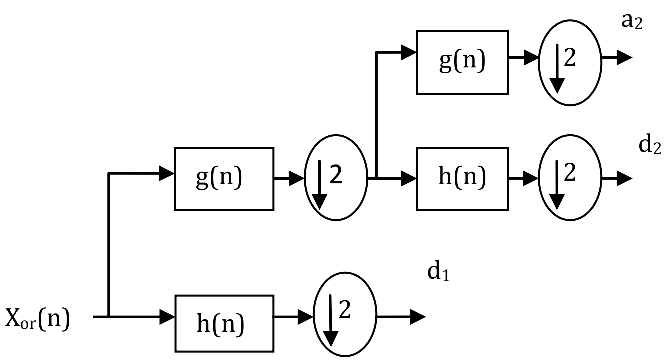


Fig - 4: Two level DWT decomposition.

The DWT of the NONROI part is taken. After taking the DWT of signal we get the coefficients, these coefficients are provided with the proper threshold to reduce the number of insignificant number of coefficients below the threshold level to zero. Now the thresholded coefficients are rounded off to remove the truncating error.

2.3 Lossless compression using RLE

The signal or the data which generally have large numbers of redundancy which can be minimized by using Running Length Encoding (RLE). RLE replaces the repeated data or samples with the value of the data or samples and frequency of repetition i.e. the number of times that data or samples are repeated. Thus reducing the number of bits required to store the data. The theresholded and rounded off coefficients are have lot of consecutive coefficients that are zero. So by using RLE the numbers of zero coefficients are grouped together thus it reduces the number bits to store these coefficients. After these we get the compressed NONROI part.

2.4 Lossless compression of ROI part

For compression of ROI part first the difference between the present sample and preceding sample is taken. By taking the difference the values of the sample reduces, thus the bit required to represent the samples will be less. After these the samples are compressed by using RLE. After the RLE we get compressed ROI part. The compressed NONROI part and ROI part constitute compressed ECG signal.

2.5 Reconstruction of ECG signal

The compressed signal contains two part ROI and NONROI part. Both ROI and NONROI parts are decoded using. The inverse Discrete Wavelet Transform (IDWT) of the compressed NONROI part is taken to get the NONROI signal. Compressed ROI part is decode using RLE and then the difference of present sample and preceding samples are take where the next present sample is updated to the difference, which gives ROI part. Both ROI part and NONROI part are combined to get reconstructed ECG signal.

3. Result and Discussion

3.1 Experiment Settings

All the 48 records of the raw ECG signal used in the experiments were taken from MIT-BIH arrhythmia benchmark database. The ECG signals are sampled at 360 Hz sampling frequency with a resolution of 11 bits. The samples are taken for a recording of 10 sec. So for 10 sec there 3600 samples present in an ECG signal.

3.2 Performance evaluation

To evaluate the performance of the compression algorithm
four major parameters are given below:-

1. Compression ratio (CR): It is defined as the ratio of the number of bits that represent the original signal to the number of bits that represents the compressed signal.

$$CR = \frac{b_{ORI}}{b_{compNOROI} + b_{compROI}} \quad (1)$$

where b_{ORI} is number of bits in original ECG signal and $b_{compNONROI}$ is the number of bits in the compressed NONROI part and $b_{compROI}$ is the number of bits in the compressed ROI part.

2. Percentage Root Mean Square difference (PRD): It is defined below

$$PRD = \sqrt{\frac{\sum_{n=1}^{N}(X_O(n) - X_R(n))^2}{\sum_{n=1}^{N}(X_O(n))^2}} \times 100 \quad (2)$$

3. Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{n=1}^{N}(X_O(n) - X_R(n))^2}{N}} \quad (3)$$

4. Signal to Noise Ratio (SNR): It is defined as signal power to noise power in db.

$$SNR = 10\log\left(\frac{\sum_{n=1}^{N}(X_O(n))^2}{\sum(X_O(n) - X_R(n))^2}\right) \quad (4)$$

where X_O and X_R are original and reconstructed signal and N is length of the signal.

3.3Result

All the 48 record from MIT-BIH are subjected to the compression using the proposed algorithm the CR , SNR, RMSE and PRD is calculated which is shown in the table-1 and table-2 where wavelet filter symlet 6 used for decomposition. The Fig-5 shows the original signal, reconstructed signal and reconstructed error.

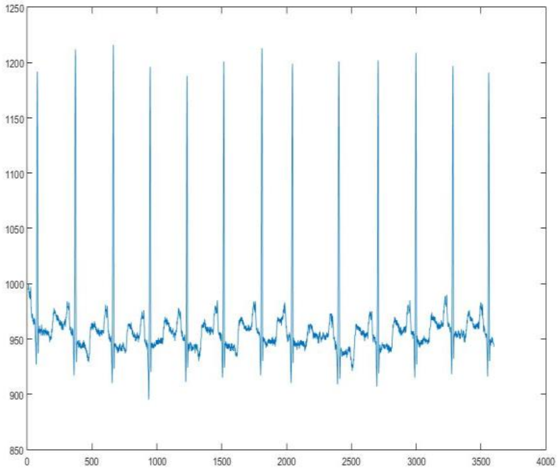
Table-1: Performance of proposed algorithm on the basis of RMSE, SNR, CR and PRD.

Records	RMSE	SNR	CR	PRD
100	4.82	45.93	14.07	0.5
101	6.86	42.88	11.62	0.71
102	7.75	41.96	11.21	0.79
103	3.59	48.61	10.1	0.37
104	11.19	38.27	9.72	1.14
105	10.5	39.24	10.04	1.09
106	14.62	36.5	11.84	1.49
107	10.24	39.37	7.37	1.07
108	7.71	41.88	11.53	0.8
109	11.85	37.89	7.56	1.27
111	8.18	41.69	12.75	0.82
112	6.69	41.73	10.21	0.81
113	9.1	40.77	13	0.91
114	9.54	40.28	14.2	0.96
115	8.99	40.28	13.13	0.96
116	19.15	32.81	9.33	2.28
117	12.03	37.03	11.03	1.4
118	10.65	37.78	8.33	1.28
119	6.44	42.23	11.01	0.67
121	4.17	46.39	15.72	0.47
122	7.88	40.78	8.88	0.91
123	13.58	35.96	18.14	1.59
124	10.48	38.38	16.39	0.97
200	6.67	41.78	11.02	0.78

Table-2: Performance of proposed algorithm on the basis of RMSE, SNR, CR and PRD.

Records	RMSE	SNR	CR	PRD
201	6.28	43.92	10.74	0.63
202	7.44	42.79	10.84	0.72
203	15.76	36.8	7.03	1.87
205	5.94	44.07	10.09	0.62
207	10.27	39.62	13.67	1.04
208	24.03	32.44	6.94	2.38
209	6.85	43.27	8.47	0.68
210	10.85	39.29	7.81	1.08
212	10.85	39.23	7.78	1.09
213	15.72	35.51	6.82	1.67
214	7.6	40.23	10.23	0.81
215	6.33	43.97	8.53	0.63
217	9.89	40.13	7.11	0.98
219	6.55	42.8	10.89	0.72
220	13.68	38.54	11.9	1.23
221	11.76	38.53	9.2	1.18
222	14.7	34.93	14.36	1.79
223	7.39	41.85	7.51	0.8
228	9.78	39.11	15.12	.79
230	9.8	39.89	7.91	1.011
231	13.07	37.73	13.65	1.29
232	9.98	39.37	20.04	.98
233	7.9	41.09	10.09	0.45
234	5.91	43.5	7.9	.52

The record 232 shows maximum compression ratio of 20.04 and record 213 shows minimum compression ratio 6.82. The average CR form table-1 is 11.58, average RMSE is 9.67, average PRD is found to be .896 and average SNR is found to be 39.89. The table-3 and table-4 shows the comparison of the proposed method with various compression schemes for record 228 and 232 respectively.



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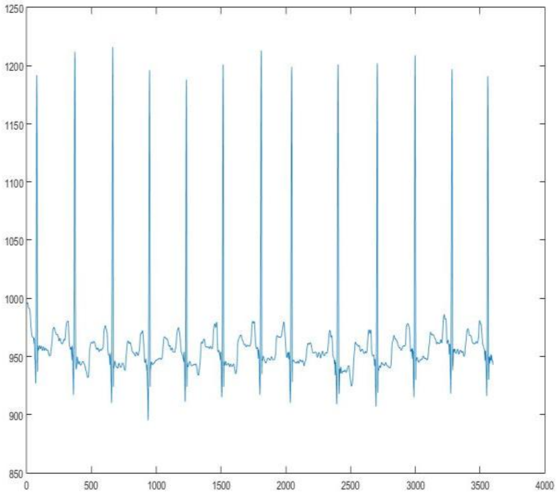

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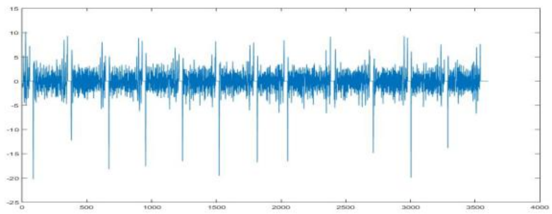

(c)

Fig-5 (a) Original ECG signal record-100. (b) Reconstructed ECG signal. (c) Reconstructed error.

Table-3: Performance compression of different algorithm for MIT-BIH record-228

Algorithm	CR	PRD	SNR
Sangjoon et al[12]	22.33	.92	17.63
Swarnkar et al[13]	25.26	2.718	22.14
Proposed algorithm	15.12	.79	39.11

Table-4: Performance compression of different algorithm for MIT-BIH record-232

Algorithm	CR	PRD	SNR
Sangjoon et al[12]	24.12	1.03	10.17
Swarnkar et al[13]	25.24	2.24	27.58
Proposed algorithm	20.04	.98	39.37

From the comparison of proposed method with other compression schemes it is found that the proposed compression schemes gives better performance in terms of PRD and SNR but have relatively less compression ratio as compared to other schemes.

4. CONCLUSIONS

In this paper a hybrid compression for compression of ECG signal scheme based on lossy plus lossless method is presented. DWT is used for compression of NONROI part and RLE is used for the compression of ROI part. The compression algorithm is tested on 48 records of duration 10 sec and evaluated on the basis of performance evaluation parameters. The compression scheme gives better PRD,SNR, and RMSE as it does the lossless compression of the clinically important QRS complex. This compression scheme gives average CR to be 11.58 which is less than the lossy method and greater than lossless method. It gives an average PRD which is .896 which is less than lossy and greater than lossless methods.

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