# ECG COMPTRESSION USING RUN LENGTH ENCODING

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## ABSTRACT

*A new approach of run length encoding (RLE) is proposed in this research to compress discrete cosine transform (DCT) coefficients of time domain ECG signals. Energy compaction property of DCT facilitates the process of length encoding by accumulating the correlative coefficients into separate segments. Thus the high probability of redundancies in consecutive coefficients facilitates the use of RLE. To increase the CR, two stages of RLE are performed on the quantized DCT coefficients. Then binary equivalent of RLE values are obtained by applying Huffman coding. Finally the distortion indices of relevant clinical diagnostic information of the reconstructed signal is measured in terms of weighted diagnostic distortion (WDD), percentage root-mean-squared difference (PRD) and root-mean-square (RMS) error indices. Results indicate that for MIT-BIH Arrhythmia database Record 117, the proposed compression algorithm can achieve a compression ratio of 14.87 with a bit rate of 185 bps.*

## 1. INTRODUCTION

Electrocardiogram (ECG) is the graphical representation of the electrical activity of human heart. It is largely employed as a diagnostic tool in clinical practice. For real-time transmission of the ECG in case of emergency medical situations, like telemedicine or telecardiology, requires application of compression techniques to reduce the storage requirements of hospital databases and ambulatory ECG data so that it can improve the speed of data transmission through low bandwidth networks, like telephone lines [1]. Compression methods used for ECG signal can be classified into three major categories as direct time-domain techniques (DTT), Transformational approaches (TA) and Parameter extraction techniques (PET) [2].

DTT methods usually rely on utilization of prediction or interpolation algorithms like amplitude zone-time epoch coding [3] and turning point [4]. TA methods usually can achieve higher compression ratio (CR), and are insensitive to noise in ECG signals [5]. Some applications of TA methods are wavelet transform [1], [2], [6], discrete cosine transform (DCT) [7], [8] and etc. Here, to obtain high CR, use of accurate QRS detection, period normalization, amplitude normalization and mean removal in [1], [2], [6] for one dimensional (1-D) and two dimensional (2-D) wavelet transforms, system becomes complex. Instead, a DCT based scalar quantizer with linear coding had achieved a good CR with excellent reconstruction quality and minimum PRD [7]. Also, DCT has the property to round off a series of small coefficients to zero without altering the signal significantly. Then application of linear encoding like run length encoding (RLE) can achieve better CR than others.

Again, up to now, researchers utilize simple mathematical distortion measures like percentage root mean squared difference (PRD), mean squared error (MSE), root-mean-squared (RMS) error etc. to evaluate the reconstructed signals quality. Among them, PRD is the most widely used index for evaluation of distortion, because of its simplicity and mathematical convenience [2]. But PRD is not a good measure of the true compression error with poor diagnostic relevance [9], as PRD has a dependency on the dc level that can introduce confusion in the evaluation of the performance of a compressor [10]. Such measures are also irrelevant from the point of view of diagnosis [9]-[13]. So, the use of a distortion measure such as weighted diagnostic distortion (WDD) index can be an effective tool for determining the performance of a compression algorithm [11]-[13]. Throughout the research work we have tried to utilize the positive impact of WDD on the relevancy of clinical diagnosis, instead of PRD.

## 2. COMPRESSION METHODOLOGY

### 2.1. Preprocessing and Segmentation of ECG signal

A block diagram of our proposed compression scheme is provided in Figure 1. According to the process flow, ECG signal is firstly segmented into two distinct parts. To facilitate the segmentation process, the 360 Hz sampled MIT-BIH ECG data sets are down sampled to 250 Hz. Then segmentation is performed on P, QRS and T locations by using the detection algorithms in [13]. Figure 2 illustrates the locations of various characteristic points of ECG signal. After recognizing the QRS complex, the T wave and P wave are identified. Finally the baseline variation is removed from the ECG signal.

### 2.2. DCT Transform

Each QRS-complex and non-QRS wave (P and T sections) is transformed to 1-D DCT separately. Due to the energy conservation property of DCT, it generates a long sequence of zeroes at higher frequency coefficients.

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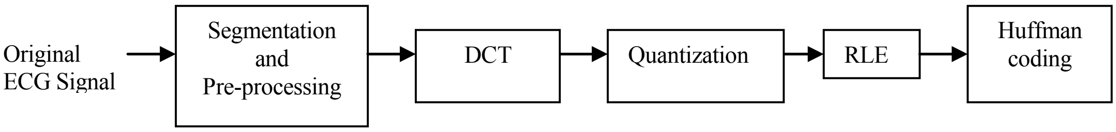


**Figure 1 -** Block diagram of our proposed compression scheme.

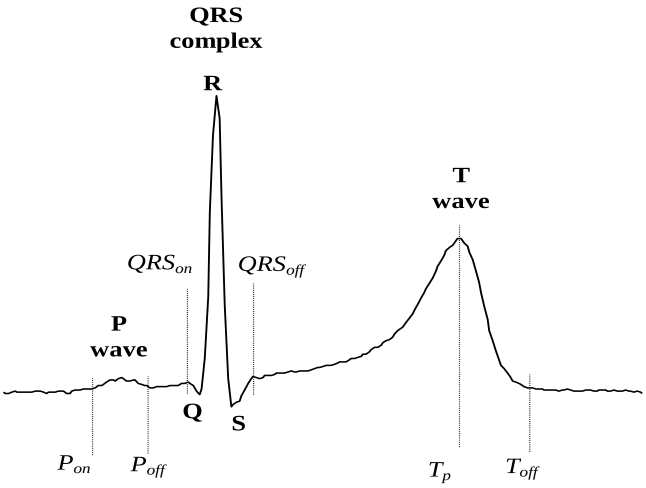


**Figure 2 -** P, QRS and T features of ECG signal.

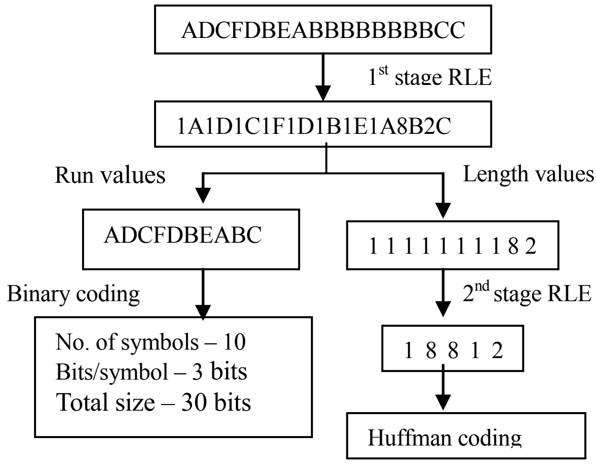


**Figure 3 -** An example of our RLE based encoding scheme.

A scalar quantizer with step size starting from 0.1, every time it is incremented by 0.1 up to the level until there introduces a significant amount of distortion in the reconstructed signal. Floating point coefficients are then modified to the single precision values.

### 2.3. Run Length Encoding

The use of quantization is always motivated by the need to reduce the amount of data to represent a signal. According to Figure 3, RLE of DCT coefficients are carried on two different stages. Each data file of quantized QRS and non-QRS DCT coefficients are encoded and then separated in the first stage of RLE. Separation of length values of RLE from run values showed an appreciable amount of redundancies suitable for further compression.

So, a second stage of RLE is applied to the length files obtained from $1^{st}$ stage. For decimal to binary conversion of all the data files, separate techniques are used for each RLE files. Run values of $1^{st}$ level DCT-RLE coefficients are binary encoded according to the Equation (1):

$$\textit{Binary bits} = \textit{no. of symbols} \times \textit{bits/symbol} \qquad (1)$$

Bits/symbol can be determined by the formula $\log_2 x$, where x is the no. of distinct symbols in the signal. Then, Huffman coding is applied to the $2^{nd}$ level RLE of lengths values for further compression. This facilitates both the compression and binary encoding.

## 3. PERFORMANCE MEASURES

### 3.1. CR and Bit rate calculation

The total size of our compressed ECG data file is consists of:

- Binary codes from the 1st stage RLE run values for each ECG beat
  - a) For P and T sections
  - b) For QRS complex
- Binary codes from the Huffman coding of the $2^{nd}$ stage RLE values for each ECG beat
  - a) For P and T sections
  - b) For QRS complex
- Combined Huffman code dictionary for all ECG beats
  - a) For P and T sections
  - b) For QRS complex

So, the CR of our proposed RLE based compression scheme is as follows in Equation (2):

$$CR = \frac{N \times m}{d_p + d_q + \sum_{i=1}^{n} (c_{p_i} + c_{q_i} + r_{p_i} + r_{q_i})} \qquad (2)$$

Here, $N$ is the no. of ECG data samples, $m$ is the no. of bits/data used in MIT-BIH database, $n$ is the no. of ECG beats, $d_p$ and $d_q$ are the dictionary size for non-QRS and QRS region respectively, $n$ is the no. of ECG beats, $c_p$ and $c_q$ are the Huffman code size for non-QRS and QRS region respectively and $r_p$ and $r_q$ are the binary code run values of RLE for P and T sections and QRS complex respectively. And the bit rate is by Equation (3):

*Bit rate = (Total no. of bits after compression)/ (Total no. of data) × (Sampling rate)* (3)

### 3.2. WDD index and parameters

Throughout the research, to evaluate the performance of RLE based compression scheme, WDD is mainly used as a distortion index other than PRD or RMS. It is used to measure the quality of the reconstructed signal by extracting some diagnostic features both from the original and reconstructed signals as shown in Equation (4).

$$WDD(\beta, \hat{\beta}) = \Delta\beta^T \cdot \frac{\wedge}{tr[\wedge]} \cdot \Delta\beta \times 100 \qquad (4)$$

Where $\beta$ and $\widehat{\beta}$ are the ECG derived characteristics parameters used for WDD index. Again, $\wedge$ indicates diagonal weighting matrix to emphasize certain parameters or regions of ECG complex. Also, $\Delta\beta$ is the normalized difference vector as defined by Equation (5) and Equation (6).

$$\Delta\beta = \frac{\left|\beta_i - \widehat{\beta}_i\right|}{\max\left\{\left|\beta_i\right|, \left|\widehat{\beta}_i\right|\right\}} \qquad (5)$$

$$\Delta\beta^T = [\Delta\beta_1, \Delta\beta_2, \Delta\beta_3, \ldots\ldots\ldots, \Delta\beta_p], \; p = [1,2,3,\ldots\ldots,18] \qquad (6)$$

Shapes, amplitudes and durations are the main characteristic features that are used for comparisons [13]. Here, 18 different characteristic parameters as indicated in Figure 4 and some of their predefined values as obtained from literature [13]. For amplitude and duration, the difference vectors are directly calculated by Equation (6), but a separate penalty matrix is used to quantify the shape deviation of original and reconstructed ECG signals in WDD calculation.

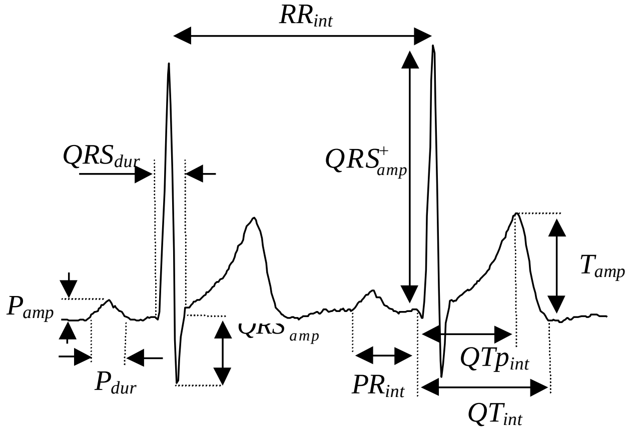


**Figure 4 -** Some of the diagnostic features of ECG.

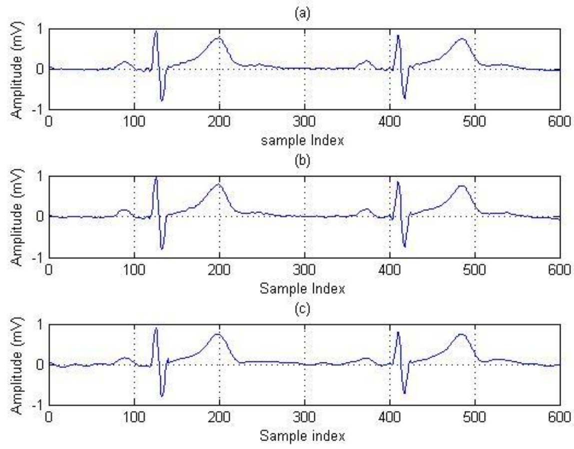


**Figure 5 -** Visual illustrations of original (a) and reconstructed ECG signal of record 117 (MIT-BIH) for CR of 10.12 (b) and 13.92 (c) respectively.

## 4. RESULTS

The effects of 2-stage RLE compression on ECG signals are presented in Figure 5 by varying the quantization step size of DCT coefficients for MIT-BIH record 117. The Figure indicates that the shape, amplitude and duration of the reconstructed ECG signals are almost identical to the original signal after a CR of around 14. According to literature [13], from the point of view of diagnosis, distortions will be in a considerable level, if we can remain within 2%-4% of WDD and 6%-9% of PRD. So, distortion indices calculated for the same database of Figure 5 are presented on Figure 6 and Figure 7 in terms of PRD and WDD with variations of CR and bit rate.

The trend of the distortion indices indicates that the bit rate below 200 bps introduces a drastic change in the quality of the reconstructed signal by the sharp upward bending. A comparison of the pattern of WDD with respect to PRD confirms that WDD is less sensitive than PRD on variations of the bit rate along with the quality of the reconstructed signal. The reason is, as WDD deals with the relevancy of the distortion with respect to the clinical acceptability, instead of mathematical calculations, it remains less sensitive to the distortion. This property of WDD facilitates our compression algorithm by offering higher compression ratios.

We have tested the performance of our proposed RLE based compression scheme for three MIT-BIH records as are 101, 117 and 119. All the three databases confirm the better results of the retrieved signal after compression. Comparisons with some other standard compression techniques are presented in Table 1 that indicates the better performance in terms of PRD and WDD indices. As application of WDD for performance evaluation of ECG compression schemes is not explored widely, for most of the comparisons we had to rely on PRD index.

## 5. CONCLUSION

Performance of a compression scheme can vary with the characteristic of the input dataset. So, for the same bit rate, our RLE based compression scheme achieves different distortion indices for different databases. According to the review cardiologists in literature, an acceptable level of reconstruction error can be maintained by a compression ratio of 15. Thus, the results indicate that our scheme is capable to attain an acceptable level of CR. Again, integration of low cost portable storage devices and digital signal processors to the proposed methodology, the system can overcome the bandwidth limitations for real-time applications.

**Table 1** - WDD and PRD variation with some other techniques from literature.

| From literature Compressor | CR | $CR_{PS}$ | PRD | $PRD_{PS}$ | WDD | $WDD_{PS}$ |
|---|---|---|---|---|---|---|
| AZTEC [13] | 6.9 | 6.73 | 15.5 | 4.358 | - | 0.857 |
| Long Term Prediction [13] | 6.9 | 6.73 | 7.3 | 4.358 | - | 0.857 |
| 1-D DCT [15] | 6.0 | 6.73 | 7.5 | 4.358 | - | 0.857 |
| | 12.0 | 11.39 | 15.0 | 9.087 | - | 1.627 |
| Cut and align beats approach with 2-D DCT [15] | 6.0 | 6.73 | 3.5 | 4.358 | - | 0.857 |
| $ASEC_{PRD}$[13] | 6.9 | 6.73 | 5.5 | 4.0 | 5.1 | 0.857 |

PS denotes proposed DCT-RLE based scheme.

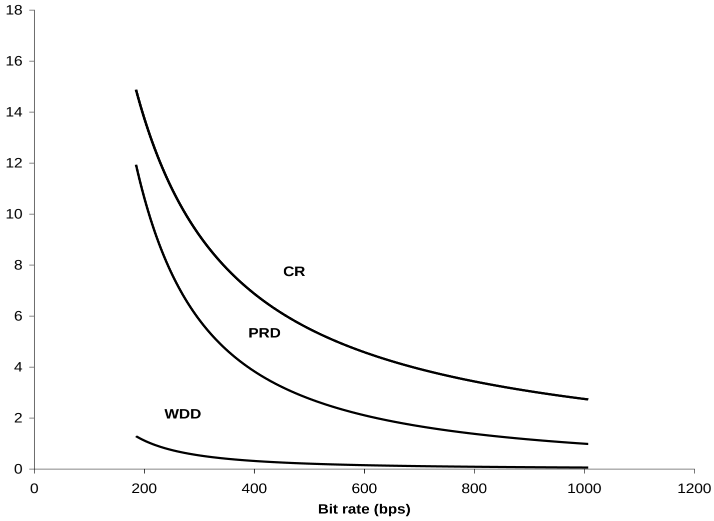


**Figure 6 -** CR and distortion-rate curves with bit rate variations of RLE based compression for Record -117.

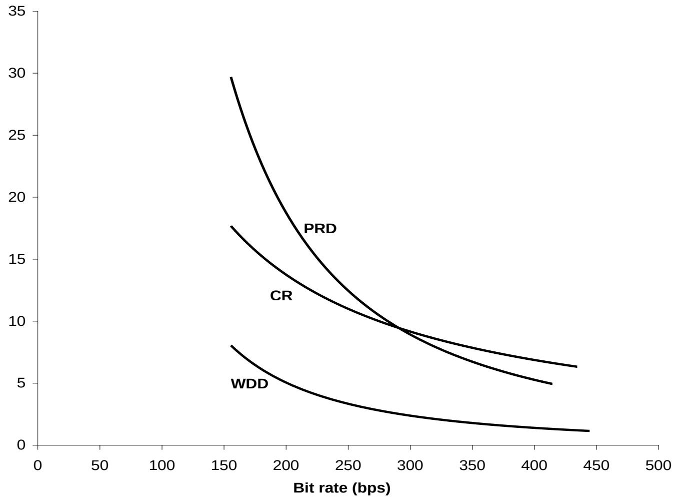


**Figure 7 -** CR and distortion-rate curves with bit rate variations of RLE based compression for Record -119.

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