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A Survey Paper on ECG Data Compression techniques and Proposing a New Method to achieve a Low PRD Value

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Abstract

Data compression has its application in many fields and so as in the field of medical science. ECG is an important parameter that measures patient's health and reports abnormalities if any. This paper has done a survey of various kinds of ECG data compression techniques. The proposed method of ECG Data Compression is intended to attain a lossless compressed data with relatively high compression ratio (CR) and low PRD (Percent Root Mean Square Difference). Different transformation may be used for data compression. This requires very less space for decompression. It also provides low noise and has excellent restoration quality. It reduces redundancy that occurs in an ECG signal. This requires very less time for decompression. It also provides low noise and has excellent restoration quality. It reduces redundancy that occurs in an ECG signal.

Keywords

ECG, Transforms, P.R.D., Compression, Restoration, C.R.

1. Introduction

ECG (electrocardiogram) is a test that measures the electrical activity of the heart. The heart is a muscular organ that beats in rhythm to pump the blood through the body. In an ECG test, the electrical impulses are generated while the heart beatings are recorded and usually shown on a piece of paper. This is known as an electrocardiogram, and records any problems with the heart's rhythm, and the conduction of the heart beat through the heart which may be affected by underlying heart disease. ECG Data Compression is required to reduce the disk space required to store the data, as ECG is a continuous data taken for a very long interval of time. Also by compressing redundant data from the signal can be removed which actually takes considerably large area in memory.

2. Existing methods

Efficient and reliable electrocardiogram (ECG) compression system can increase the processing speed of real time ECG transmission as well as reduce the amount of data storage in long-term ECG recording. A fast correct diagnosis would decrease the consequences of the disease. Few existing methods are discussed here.

2.1 R Peak Detection Algorithm

This algorithm is developed using differentiation technique [1]. It is basically a high-pass filter which allows high frequency components (QRS complex) to pass through while attenuate low frequency components such as P and T waves. Every voltage value in the original ECG file is subtracted from its preceding. In the flat or low frequency region, this difference will be close to zero where as higher differences (positive or negative) results in QRS region of high frequency. Now these differenced voltage values are squared, to shift the whole ECG signal in positive half, as the slope of QRS complex may vary over leads. Exact 'time' of the appearance of the maximum squared voltage is noted [1]. At last, on that time span (60 ms) before and after the maximum (squared voltage), the maximum voltage value is searched from the original ECG data file.

2.2 ECG compression using different Wavelet transforms and PDLZW method

The proposed method illustrates a mixture system supported on the arrangement of the Parallel Dictionary Lempel-Ziv-Welch (PDLZW) method and the wavelet transform that gives effectual cardiogram volume reduction [2]. Primarily data for signal is loaded and then the ECG signal is wavelet transformed. The different families of wavelets like Haar wavelet, Symlets, Daubechies wavelets, orthogonal wavelets; Coiflets are used and compared [3].

2.2.1 Discrete Wavelet Transform (DWT): The DWT is based on the tree structure with D levels that can be implemented by using an appropriate bank of filters [2]. It is possible to follow two strategies that differ from each other basically because of the criterion used to extract strings of data samples to be elaborated by the bank of filters.

2.2.2 PDLZW Encoding: The PDLZW encoding algorithm consists of m variable word width dictionaries. Each variable has a word width of 1 byte [2, 3]. The variables are numbered from 0 to m-1.The information correlation property of the application gives the actual size of the dictionary set. Best possible dictionary is set from a number of simulations for exploring information correlation properties.

2.2.3 PDLZW Decoding: Reverse operation of PDLZW encoding algorithm is used to reconstruct the original string from the encoded one. The compressed codeword reads out the original string from the dictionary [2]. Same contents are placed in the dictionary sets of both algorithms in order to perform the operation without any loss. The last output string after concatenation will be the first character of the present output String[2, 3].

2.3 ECG data compression for WBAN

A compression method providing high CR with small distortion can reduce the cost of the wireless data transmission, and make it possible for prolonged local data storage at individual sensors until the detection of an emergency [5]. However, existing ECG data compression approaches either do not achieve both high CR and small distortion, or provide these at very high complexity. On the other hand, low complexity is essential for wireless health monitoring sensors running on batteries, whose power efficiency and endurance can be life-critical. In this section, we propose a simple but highly effective ECG data compression method [5]. Existing data compression techniques for ECG signals can be classified into three main categories:

1) Direct data compression methods,
2) Transformation methods, and
3) Parameter extraction methods.

For the transformation methods, discrete cosine transforms (DCT) and wavelet transforms have been widely investigated for lossy data compression [5]. This method is a 2-stage data compression process that combines a lossy data compression technique and a lossless coding scheme. Here, the DCT-based transform is used in the first stage of the compression process due to the fact that the frequency of ECG signal concentrates mainly between 0.05 Hz and 130 Hz. Therefore, through DCT transform, the original ECG signal can be represented in a few transformed DCT coefficients, which can achieve higher CR and is insensitive to noise effect. In addition, the DCT-based method is simpler than wavelet based compression and more flexible to control the CR. After the DCT, the LZW coding is used in order to compress the DCT coefficients in the second stage of the compression process [5]. LZW coding is a lossless dictionary based compression algorithm which looks for repetitive sequences of data and builds a dictionary based on them. Since it is a lossless compression, the percentage root-mean-square difference (PRD) can be well conserved. Therefore, the whole process of the ECG data compression can be summarized as follows:

1) Split the original signal into *M* blocks, each containing *N* samples;
2) Transform each block using DCT;
3) Retain *K*(*N*) DCT coefficients;
4) Quantize the *K* retained DCT coefficients;
5) Encode the quantized DCT coefficients using LZW coding [5].

To facilitate comparisons with existing approaches, the PRD is employed to measure the data reconstruction error:

$$PRD = \sqrt{\frac{\sum_{n=0}^{N-1}(x_n - \bar{x}_n)^2}{\sum_{n=0}^{N-1} x_n^2}} \times 100 \qquad (1)$$

Where x_n *is* the original data and $\bar{x}_n$ is the reconstructed data after compression. In the simulation, each block contains 1000 samples and 180 DCT coefficients are retained for each block.

ECG data compression using energy compression and run length algorithm

A compression algorithm decreases the data samples in such a way that the diagnostic information in the reconstructed signal would be retained from the compressed data. In this approach, ECG data is compressed using DCT and run-length algorithm

2.4.1Compression algorithm

a) Energy Compression:

By eliminating all the coefficients that are smaller than a threshold T to achieve compression, we would encounter distortion in certain aspects of the reconstructed signal [6]. But because of the energy invariance property of orthonormal DCT which is defined as:

$$\sum|x(n)|^2 = \sum|X(k)|^2 \qquad (2)$$

where x[n] is the signal to be analyzed and X[k] denotes the DCT coefficients, setting threshold does not create significant distortion in the reconstructed signal [6]. Referring to previous approach, the following steps can be utilized for the entropy compression. Here thresholds are selected based on the percentage quantity that represents a measure of the total preserved energy after setting the threshold with respect to the total energy before setting the threshold [6]. The following steps briefly review the algorithm:

a) Calculate the total energy E in the DCT coefficients X

$$\mathrm{E} = \sum \mathrm{x}^2 \qquad (3)$$

b) Calculate desired retained energy E'.

c) Form a sequence X[k] by sorting the magnitudes of the DCT coefficients in descending order.

d) Use the following pseudo code to find the desired threshold: set energy = 0 set k = 0
while energy < E'
energy = energy + (X[k])2 k = k+1
end threshold = X[k-1]

e) Sort the sequence according to its indices.

b) Run Length Algorithm

After calculating the threshold T, all the coefficients that are less than T should become zero. Because of the energy compaction property of DCT and the fact that most of the adjacent higher frequency components are zero, we used the run-length algorithm for this part to deduct redundant data caused by energy compression [6]. This helped us to get a suitable compression ratio while keeping the root mean square difference (PRD) unaffected [6].

2.5 ECG Compression Algorithm Based on Back Propagation Artificial Neural Network

ECG compression is an important feature in bio-signal processing. BP Artificial neural network is used for ECG data compression because the compression precision and compression ratio are high but the compression speed is low [8]. The rate of compression is improved by combining BP with Training Performance algorithm by establishing a weight template library.

2.5.1 BP ECG compression

BP neural network can be used to compress ECG signals because ECG signals are quasi-periodicity signals. The difference between cycles is little. When BP neural network is used to study each cycle of ECG waves, the little change between cycles can be expressed with hidden units' values, and weights don't change [8]. So we can only store hidden units' values: If the number of hidden units is smaller than the number of input data, data is compressed. Three layer BP neural networks can be adopted to compress ECG data. The number of input neural units and the number of output equal the number of sampling points in an ECG cycle. The input unit number and the output unit number should be dynamic because heart rates are different for different persons or different time of the same person [8]. Average heart rate of a patient through automatic measurement, and the number of sampling points in an ECG cycle is obtained. The number represents input and output unit numbers the partition of ECG cycles is based R points. We take the points among T1/3 before a R point and 2T2/3 after the R point as one cycle (T1 is the space between the current R point and the previous R point; T2 is the space between the current R point and the next R point) [8]. An R point's value is fixed on some input unit. If the point number of ECG cycles is different from the 'input unit number and the output unit number, it can be processed differently according to the extent of the difference. (1). If the difference is small and the number of ECG sampling points is smaller than the number of input units, suitable values to supply deficiencies of the input units can be used[8]. If the difference is small and the number of ECG sampling points is bigger than the number of input units, we take one point every other point in the foreparts and the tails of cycles and keep the number of input data to equal the number of input units.(2). If the difference is big, the number of input neural units according to the heart rate can be changed.

The neural unit number of hidden layer is 2. It is enough to express the difference of the same kind of ECG waves of the same person because there is little change between the ECG waves. The impermanent and highly aberrant ECG data are stored directly and flags are added to distinguish them from compressed data [8]. When the number of continuous highly aberrant ECG cycles is more than five, the new weights are figured out. In order to improve the speed of convergence and shorten the compression time, improved algorithms can be adopted out to accelerate the convergence:

1).Adopt improved weight modification algorithm

$$W_{kj}(t+1) = W_{kj}(t) + \varepsilon.\delta_k.H_j + \eta\left(W_{jk}(t) - W_{jk}(t-1)\right) \qquad (4)$$

$$\mathrm{W_{jk}(t+1) = W_{jk}(t) + \varepsilon.H_j\left(1 - H_j\right)\sum_{k=0}^{N-1} \delta_k W_{kj}(t) + \delta(W_{jk}(t) - W_{jk}(t-1))} \qquad (5)$$

$$\delta_k = O_K(1 - O_K)(O_k - I_K) \quad (6)$$

ε is the step size, η is a parameter that adjust variation when ε equals 0.1-0.9, η equals 0.7 - 0.9, the exact values are decided in practice [8].(2).Adopt variable step size during compressing data, variable step size can be adopted to accelerate the convergence. The formula is the following

$$\Delta\varepsilon_r = \begin{cases} +k & \Delta Er < 0 \text{ three times continuous} \\ -\emptyset\varepsilon & \Delta Er > 0 \\ 0 & \text{others} \end{cases} \quad (7)$$

Δ Er is the error variation, k and φ are suitable constants.

2.5.2 Combine BP algorithm with 'IP algorithm

BP algorithm usually reaches convergence after hundreds of iterations. If the amount of work of each training is cut down, it will benefit shortening the compression time greatly. To cut down the amount of work of each training [8]. We combine BP algorithm with TP algorithm to compress ECG data. TP algorithm is simple. It has high speed of execution and high fidelity. Its compression ratio is about 2: 1. TP algorithm is based on the following facts [8].

(1). According to the sampling theory. It is enough to adopt 100 HZ frequency to sample ECG data whose bandwidth is 407Hz. (2). If 100HZ sampling frequency is adopted, there were aberration of peaks or missing small waves in QRS waves with high amplitude and high slope because of omission of key points [8] . Except for high frequency signals that are significant to clinic, it is enough to adopt 100HZ sampling frequency to sample ECG waves. TP algorithm is the following. The first sampling point's value is Y0; the next two points' values are Y 1 and Y2.

$$If\ (Y_2 - Y_1 \times\ Y_1 - Y_0) < 0\ then\ Y_0 - Y_1$$
$$If\ (Y_2 - Y_1 \times\ Y_1 - Y_0) > 0\ then\ Y_0 - Y_2 \quad (8)$$

TP algorithm is used to process data before using BP algorithm. The number of points in each ECG cycles after using TP algorithm is half the number before. The input and the output neural unit number are half the before, which cut down the amount of work of each training and shorten the compression time greatly [8]. TP algorithm is that take one every other point except key points, so flags must be added to distinguish key points from other points in order to reconstruct the waves later [8].

3. Proposed Method

This proposed method is mainly focused on reducing Percent Root-mean-square Difference (PRD) to an extremely low value by maintaining sufficiently large Compression Ratio (CR). In that regard an extensive survey has been made to analyse the outcome

The CR and PRD of few of the existing methods are as shown in Table 1.

Table.1: Comparison of various compression techniques

Method	PRD %	CR
R-Peak detection and ASCII character encoding [1]	7.55	23.1
PDLZW method Compression [3]	--	13:1
Run-Length Algorithm [6]	1.1413	6.99
Compression based on Artificial Neural Network [8]	1.414	6.99

As we infer from the survey vector quantization provides a high CR with a lossy compression and on the other hand DPCM being lossless yields a low CR. Hence this paper proposes a combination of vector quantization and DPCM compression technique.

3.1 Proposed Algorithm:

An ECG signal is mainly composed of P-QRS-T waves as shown below:

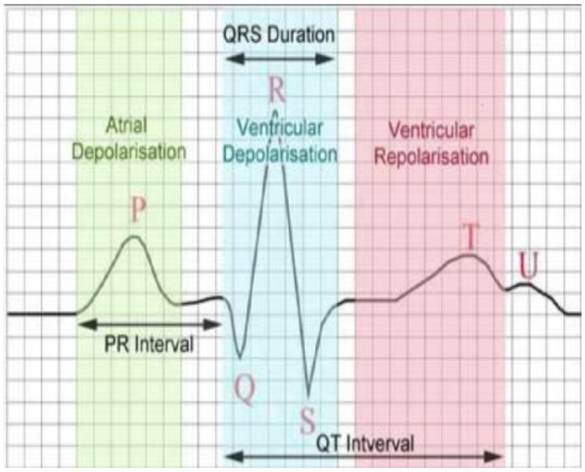

Fig.1: ECG signal

The shape and size of the P-QRS-T wave and the time intervals between various peaks contains useful information about the nature of disease afflicting the heart.

(1) The raw ECG signal is initially subjected to pre-processing using ADS1298 digital filter to get rid of interference that affect the quality of signals.
(2) The QRS complex and PT waves are segregated using a combination of R-peak detection and Run-length algorithm.
(3) The QRS complex is subjected to DPCM compression technique so that no critical information is lost, hence low PRD is achieved.
(4) The PT waves are then vector quantized to obtain high compression ratio (CR).
(5) The results obtained from DPCM compression technique and vector quantization are subjected to Huffman encoding.
(6) Similar decoding and de-quantization techniques are employed at the reception, thereby reconstructing the original ECG signal.

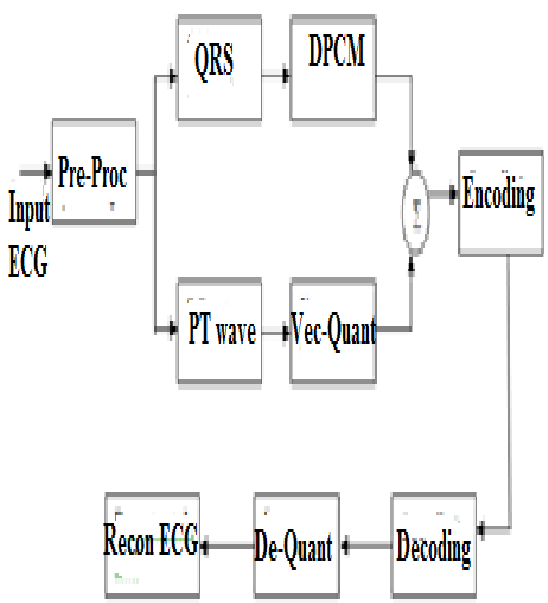

Fig.2: Block diagram of the proposed algorithm

4. Conclusion

The proposed method thus provides efficient compression as it uses vector quantization and also low PRD in QRS region as it uses lossless DPCM. Thus the critical data which is present is retained without any loss and will be available for clinical use. Also as CR is high due to vector quantization it can be stored in less memory and can be wirelessly transmitted.

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