Study of Different ECG Signal Compression Techniques

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Abstract: ***Electrocardiogram (ECG), is the process of recording the electrical activity of the heart over a period of time using electrodes placed on a patient's body. The signal collected from the body needs to be processed and compressed before sending to monitoring center. Data compression is the process of reducing the number of bits needed to store or transmit the required data. Compression can be either lossless or lossy. Losslessly compressed data can be decompressed to exactly its original value. This paper presents a study of different compression techniques for ECG data compression.***

Keywords: Electrocardiogram (ECG), Compressed Sensing, Discrete Wavelet Transform (DWT), Compression Ratio (CR).

1. Introduction

Heart diseases are becoming one of the major cause of death whole over the world. Healthcare expenses are expected to increase in the coming years. Early detection and prevention of diseases can improve the quality of life and reduces these expenses. Electrocardiogram (ECG), is used to monitor the cardiac health of a person. It is a diagnostic tool that is constantly used to record the electrical and muscular functions of the heart. An ECG signal consists of mainly 5 points, namely P,Q,R,S and T. The P wave represents depolarization of atria and its duration is less than 80ms. The QRS complex represents the left and right ventricular depolarization and its duration is 80 – 100ms. The T wave represents repolarization of the ventricles and duration is 160ms. There is a U wave in ECG signal which is having a very low amplitude or even more often is absent. The normal heart rate is 60 – 100 beats per minute. Heart rate slower than 60 beats per minute is called bradycardic and a heart rate faster than 100 beats per minute is called tachycardic.

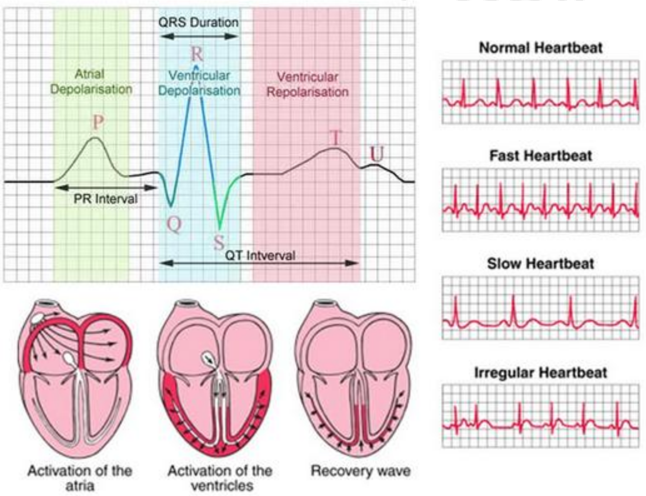

Figure 1: An ECG signal representation

An ECG signal representation is shown in Fig.1 [1]. The ECG signal obtained from the patient are processed and compressed before transmission to a monitoring center. The main objective of data compression is to reduce the number of bits so that it reduces the cost of transmission and increases storage capacity. The ECG signal, which is digitized, is compressed as much as possible such that its reconstruction should provide a clinically acceptable signal. The main goal of compression methods is that it should maintain all the useful information in the signal while compressing. For achieving such a result, the best preferred method is lossless compression technique. Even though lossless compression techniques does not provide a good compression ratio (CR), it is most accepted in case of biomedical signals. This paper discuss about different lossless data compression techniques.

The rest of the paper is organized as follows. Different ECG data compression techniques are presented in Section II, different parameters of compression in section III and section IV concludes the paper.

2. Different Types of ECG Data Compression Techniques

2.1 Simple Bit Packaging Scheme

This is a lossless data compression technique. In this method a simple coding- packaging scheme is adopted. It provides a fixed length 16-bit output. The signal is initially bit clipped in order to get minimum width 2's C representation. This scheme can be used to pack data variable length data to produce a 16-bit fixed length data. Each individual sample in the ECG signal is marked with a unique header according to the number of bits in the sample [2]. This also helps while decoding the data. The different headers used for packaging is listed in Table I.

Table 1: Headers used for Packaging

Frame Type	*Header*	*Data (Bits)*
A	1	5 or 4
B	01	7 or 6
C	0001	3
D	0000	2
E	0011	12

Each samples of ECG signal is considered. The algorithm first checks the first sample and according to the number of bits of the sample, headed is selected. Before adding the header, the 2's complement of the data is found out and is converted into binary form. Since most of the samples centers around zero value, it can represents only a few bits and hence it is necessary to retain LSB's and remove MSB's that do not carry any information. Header is added to the data. Similarly it is done for all the samples and the entire data is combined into a single output data. The coded data is transmitted to the monitoring center and the same table can be used to decode the data and reconstruction of signal is done.

2.2 Compressed Sensing (CS)

The Compressed Sensing (also known as compressive sensing, compressive sampling, or sparse sampling) is a signal processing technique for efficiently acquiring and reconstructing a signal, by finding solutions to underdetermined linear systems. This is based on the principle that, through optimization, the sparsity of a signal can be exploited to recover it from far fewer samples than required by the Shannon-Nyquist sampling theorem. There are two conditions under which recovery is possible. The first one is sparsity which requires the signal to be sparse in some domain. The second one is incoherence which is applied through the isometric property which is sufficient for sparse signals. MRI is a prominent application. By employing compressive sensing the complexity in compression techniques can be further reduced by reducing the number of digital signal processors used as compared to simple coding packaging scheme.

Here a single-lead compression method is used. It is based on the quasi-periodic nature of the ECG signal, obtained from the correlation between samples of adjacent beats. The method starts with a pre-processing stage. Here a sliding window is used and the joint sparsity pattern of heart beat is determined by the fixed length of the window. The length of the window should be short in order to generate an approximate real time transmission. Six ECG signal samples are taken and it is normalized. After normalizing it is organized in a N x 6 matrix, where N is the signal length. Compressed sensing produces compressed signal without going through intermediate stage [3].

2.3 Discrete Wavelet Transform (DWT)

A wavelet is a wave-like oscillation, whose initial amplitude is at zero, increase gradually and returns back to zero. The discrete sampling of wavelets are called wavelet transform. ECG signals are time varying signals and are non-stationary. Wavelets allow both time and frequency analysis of signals. Energy of the wavelet is concentrated in time and still it has wave like nature. ECG compression can be of three types mainly: direct time domain techniques, transformed ECG compression methods and optimization methods. Wavelet transform is a type of transformed compression method.

Wavelet transform is widely used because of its non-stationary and localized property and it can see through the signals at different resolutions [4]. The fundamental idea of wavelet transforms is that the transformation should allow only changes in time extension, but not shape. Wavelet transform produces many coefficients and these can then be compressed more easily because the information is statistically concentrated in just a few coefficients [5].

The wavelet transform is defined as:

$$[W_\varphi f]\,(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} \varphi\left(\frac{x-b}{a}\right) f(x)\, dx \qquad (1)$$

The wavelet coefficients c_{jk} are then given by:

$$c_{jk} = [W_\varphi f]\,(\,2^{-j}, k2^{-j}\,) \qquad (2)$$

2.4 Huffman Coding

Huffman code is an optimized prefix code that provides shortest average codeword length. Since it is a prefix free code, decoding process is simple. More frequently occurring symbols are associated with short codewords and less frequently occurring symbols with long codewords. Major drawback is that the hardware complexity is very high. Selective Huffman coding encodes only most frequently occurring symbols, while the other symbols remain unencoded. This further reduces the hardware complexity. Another method called Modified Huffman coding method is used for compressing ECG signal. Here the initial code for all symbols will be fixed. A new symbol will be the first transmitted symbol which indicates the appearance of a new symbol. At each time when a new symbol appears this symbol code is send [6].

Huffman coding is of two types: Static and Dynamic. Static Huffman coding uses a look-up table that has the pre-defined frequency of each character in the alphabet. Dynamic Huffman coding calculates the frequency of the character based on the data to be compressed [7].

3. Different Parameters of Compression

3.1 Compression Ratio (CR)

The Compression Ratio (CR) is defined as the ratio of number of number bits representing the original signal to the number of bits required to represent compressed signal. A high compression ratio is actually preferred. Compression Ratio can be increased by reducing the redundancy in the bits. This also reduces the data storage requirements. Compressed data must also represent the data with better fidelity while achieving high compression ratio. The CR is given by:

$$\text{CR} = \frac{\text{Bit Rate of Original Signal}}{\text{Bit Rate of Compressed Signal}} \qquad (3)$$

Table 2 shows bit compression ratio for different ECG tapes from MIT/BIH database using simple bit packaging scheme [2].

Table 2: Bit Compression Ratio for different ECG tapes of MIT/BIH database

ECG Tape	*Bit Compression Ratio*
101	2.2858
102	2.2962
105	2.2533
200	2.2572
213	2.2962
234	2.3855

3.2 Root Mean Square (RMS)

Defining error criterion is one of the most difficult problem in ECG signal compression and reconstruction. Root Mean Square (RMS) is used to evaluate the quality of compression algorithm and it is also used as an error estimate. The RMS is defined as:

$$RMS = \sqrt{\frac{\sum_{n=1}^{N}(x(n)-\widetilde{x(n)})^2}{N}} \quad (4)$$

3.3 Percentage Root mean square Difference (PRD)

The distortion in ECG signal is measured using PRD. It measures the distortion between the actual signal and the reconstructed signal. PRD is measured as:

$$PRD = \sqrt{\frac{\sum_{n=1}^{N}(x(n)-\widetilde{x(n)})^2}{\sum_{n=1}^{N}x^2(n)}} \times 100 \quad (5)$$

Where x(n) and $\widetilde{x(n)}$ are the original and reconstructed signals of length N, respectively. The PRD indicates reconstruction fidelity by point wise comparison with the original data.

Another definition of error measure called PRD1, is same as PRD but it subtracts the average value of the signal from the signal in the denominator and is given by

$$PRD1 = \sqrt{\frac{\sum_{n=1}^{N}[x(n)-\widetilde{x(n)}]^2}{\sum_{n=1}^{N}[x(n)-\bar{x}]^2}} \times 100 \quad (6)$$

$\bar{x}$ is the average value of the signal.

The PRD is an error measurement that indicates the reconstruction fidelity with original data [8] [9].

3.4 Signal to Noise Ratio (SNR)

Basically signal to noise ratio (SNR) is an engineering term for the power ratio between a signal and noise. It is expressed in terms of the logarithmic decibel scale [9].

$$SNR = 10\ log_{10}\left[\frac{E_{Signal}}{E_{Noise}}\right]^2 \quad (7)$$

$$SNR = 20\ log_{10}\left[\frac{E_{Signal}}{E_{Noise}}\right]^2 \quad (8)$$

Where E_{Signal}: Root mean square amplitude of the signal

E_{Noise}: Root mean square amplitude of the noise

4. Conclusion

The survey includes the works and findings done by various researchers on ECG signal compression techniques. Data compression is done in order to reduce the number of bits to be transmitted. Even though lossy compression techniques provide higher compression ratios (CR), lossless schemes are preferred in case of biomedical signals. The survey also includes different parameters of compression. When the compression ratio increases the cost of transmission of the data to the monitoring center also reduces.

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