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ECG DATA COMPRESSION: PRINCIPLE, TECHNIQUES AND LIMITATIONS

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ABSTRACT

Electro-cardiogram (ECG) signal is widely used in diagnosis and survival analysis of most of the cardiac diseases. ECG compression becomes mandatory to effectively/efficiently store and retrieve the data from patient database. Recently numerous research and techniques have been proposed for efficient compression of ECG signal. The proposed compression algorithms have achieved the goal in electro-cardiogram compression. However techniques that give better compression ratio (CR) and less loss of data in the reconstructed signal are always required. In this paper, we discuss various techniques proposed earlier in literature for compression of an ECG signal and provide comparative study of these techniques.

Keywords—ECG, Compression Ratio (CR), Empirical Mode Decomposition (EMD), Percentage Mean Square Difference (PRD).

I. INTRODUCTION

Electrocardiography (ECG) is the biomedical process of recording the electrical activity of the human heart over a period of time using number of electrodes placed on a patient's body. These electrodes detect even the tiny electrical changes on the skin that arise from the muscle of the heart depolarizing during each heartbeat. In the conventional twelve lead ECG, 10 electrodes are kept on the patient's limbs and on the surface of the chest. The overall magnitude of the heart's electrical potential is then measured from twelve different angles ("leads") and is recorded over a interval of time (usually 20 seconds). In this way, the all over magnitude and direction of the heart's electrical polarization is captured throughout the cardiac cycle. The graph of voltage versus time produced by this noninvasive biomedical procedure is known as an electrocardiogram. During each human heartbeat, an ECG signal conveys a large amount of information about the structure of the human heart and the function of its electrical conduction system [1].

Electrocardiogram is also known as basic clinical diagnostic medical tool for detection of the cardiac arrhythmias. As ECG signals are generally acquired over larger time periods at very high resolution and thus are highly data intensive. This results to the requirement of large storage space for database construction and more transmission bandwidth for remote ECG signal analysis, respectively. Successive ECG beats and sample values however, show some redundancy along with the information content. By removing this redundancy, ECG signal compression can be achieved.

Data compression of an ECG signal is used in for remote signal analysis where patient is somewhere else and physician is somewhere else far away from the patient. ECG signal compression systems are generally based on frequency transformation and parameter extraction techniques. When data is compressed, the goal is to reduce redundancy, leaving only the informational content. By using data compression techniques, it is possible to remove some of the redundant information contained in signal, thereby requiring less storage space and less time to transmit. Thus, one possible approach to decrease the necessary amount of storage and required transmission bandwidth is to work with compressed ECG signals [2].

The effectiveness of an ECG compression technique is described in terms of:

1) Compression Ratio (CR): Compression Ratio is defined as the ratio of the original data to compressed data without taking into account parameters like sampling frequency, bandwidth, precision of the original

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data, reconstruction error threshold,, word-length of compression parameters, lead selection, database size, and noise level. It is given by:

CR = Original file size / Compressed file size

Higher the CR, smaller the size of the compressed file.

2) PRD: Percentage Mean Square Difference (PRD) is a factor that measures the error loss. Therefore it evaluates the distortion between the original signal and the re-constructed signal. PRD calculation is as follows:

PRD = √Σ (Xi – Xi1)2 / Σ Xi2

Where Xi is the original file and Xi1 is its reconstructed version.

I. ECG COMPRESSION ALGORITHMS

There are many techniques/methods to classify ECG compression techniques. Each method has its own advantages and disadvantages. Each technique gives different value of compression ration and PRD. The techniques of ECG compression are classified as:

(a) Fast Fourier Transform (FFT)

By utilizing Fourier transform (FFT) we can obtain the frequency – amplitude of a ECG represented signal.

$$X(K) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi nk/N}$$

For k = 0, 1, 2, 3, 4, 5…………….N-1. X (K) is the FFT of a signal x (n).

The FFT compression algorithm has

- Partition the ECG signal components into three components x, y, z.
- Obtain the frequency and time between two samples of ECG signal.
- Apply the FFT and check for FFT coefficients (before compression) = 0, increment the counter A if it is between +25 to-25 and assign to Index=0.
- Check for FFT coefficients (after compression) =0, increment the Counter B.
- Calculate inverse FFT.
- Calculate the compression ratio CR and PRD.

Limitation of FFT is it fails to gives the information regarding the exact location of frequency component in time [3].

(b) Discrete Cosine Transform (DCT)

In Discrete Cosine Transform compression, signal information can restore in a restrict number of DCT coefficients.

The DCT Compression Algorithm

- Partition the ECG components into three components x, y, z.
- Obtain the frequency and time between two samples.
- Apply the DCT to ECG signal and check DCT coefficients (before compression) = 0, increment the counter A if it is between +0.22 to -0.22 and assign to Index=0.
- Check for DCT coefficients (after compression) =0, Increment the Counter B.
- Calculate inverse DCT.
- Calculate the compression ratio CR and PRD.

The Limitation of DCT is that Distortion is more in reconstructed signal.

(c) Discrete sine Transform (DST):

A discrete sine transform (DST) is a finite sequence of data points in the terms of a sum of sine functions oscillating at different frequencies. DST compression technique changes time domain ECG signals into frequency domain ECG signals without the loss of original information. DSTs are also important to numerous applications in the field of science and engineering, from lossy compression of audio (e.g. MP3) and images (e.g. JPEG) (where small high-frequency components can be discarded), to biomedical signals to spectral methods for the numerical solution of partial differential equations. The use of sine functions is a bit easier for compression. The goal of ECG compression techniques is to achieve a reduced information rate, while preserving the relevant diagnostic information in the reconstructed signal.

The DST compression algorithm

- Partition the ECG components into three components x, y, z.
- Obtain the frequency and time between two samples.
- Apply the DST of ECG signal and check for DST Coefficients (before compression) =0, increment the counter A if it is between +15 to-15 and assign to Index=0.
- Check for DST coefficients (after compression) = 0, increment the Counter B.
- Calculate inverse DST.
- Calculate the compression ratio CR and PRD.

(d) Discrete Cosine Transform-2 (DCT-2):

The one of the variant of discrete cosine transform is the DCT type-2. The DCT-2 is defined as a real, orthogonal, linear transformation. It is a special case of the discrete Fourier transform (DFT) with real inputs

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of certain symmetry. It means that any FFT algorithm for the DFT leads immediately to a corresponding fast algorithm for the DCT-2 simply by discarding the redundant operations [4].

- Partition of data sequence x in N_b consecutive blocks bi, i =0, 1, ¼.., N_{b-1}, each one with L_b samples.
- DCT computation for each block.
- Quantization of the DCT coefficients.
- Lossless encoding of the quantized DCT coefficients.

(e) Wavelet Transform:

Wavelet Transform (WT) decomposes the ECG signal into multiple frequency bands. Wavelet transformation resolve the resolution problem as its having multi resolution capability. There are two types of wavelet transform; Continuous Wavelet Transform (CWT) and Discrete Wavelet Transform (DWT). DWT is easy to implement and has the advantage of extracting no overlapping information about the signal than CWT. Wavelet transform compresses all kinds of ECG with average PRD and average compression ratios [5].

II. RELATED WORK

Many ECG data compression and its techniques have been proposed in the literature. Manuel Blanco-Velasco et. al. shows that if the performance of an ECG coder is evaluated only in terms of quality, considering exclusively the PRD parameter, incorrect conclusions can be inferred. The objective of this work is to propose the joint use of several parameters, as simulations will show, effectiveness and performance of the ECG coder are evaluated with more precision, and the way of inferring conclusions from the obtained results is more reliable. T. Padma, M. Madhavi Latha [6], A. Ahmed analyze the ECG signal for various parameters such as heart rate, QRS-width, etc. Then the various parameters and the compressed

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signal can be transmitted with less channel capacity. It was found that DCT is the best suitable compression technique with compression ratio of about 100:1

H. Khorrami, , M. Moavenian [7] proposed and compared use of CWT (Continues Wavelet Transform) with two powerful data transformation techniques DWT (Discrete Wavelet Transform), and DCT (Discrete Cosine Transform) which have already been in use, in order to improve the capability of two pattern classifiers in ECG arrhythmias classification. The classifiers under examination are MLP (Multi-Layered Perceptron, a conventional neural network) and SVM (Support Vector Machine). The training or learning algorithms used in MLP and SVM are Back Propagation (BP) and Kernel–Adatron (K–A), respectively.

S. Akhter ; M. A. Haque **[8]** proposed a new approach of run length encoding (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.

Shinde, A.A. ; Kanjalkar, P. [9] provides a comparative study of Fast Fourier Transform (FFT), Discrete Cosine Transform (DCT) and Wavelet Transform (WT) transformations is carried. Records selected from MIT-BIH arrhythmia database are tested. For performance evaluation Compression Ratio (CR), Percent Root Mean Square difference (PRD) and Signal to Noise Ratio (SNR) parameters are used. Simulation results show that using FFT low PRD and high SNR is achieved. DCT increases CR by 58.97% than FFT. WT further increases CR by 31% than DCT with low PRD value. It shows that ECG data compression using wavelet transform can achieve better compression performance than FFT and DCT.

A. Bendifallah 1; R. Benzid 1 ; M. Boulemden [10] present an improvement of a discrete cosine transform (DCT)-based method for electrocardiogram (ECG) compression. The appropriate use of a block based DCT associated to a uniform scalar dead zone quantize and arithmetic coding show very good results, confirming that the proposed strategy exhibits competitive performances compared with the most popular compressors used for ECG compression.

A. Agarwal , A. Sharma [11] **i**n this paper the Frequency Transformation Techniques, DCT and the DCT 2, are proposed for achieving these required conditions based on MATLAB Programming for Standard MIT-BIH Database Record Signal No 100/ML II ECG and the high compression and low error are achieved from this work.

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R. Mahajan ; D. Bansal provides implementation of hybrid ECG signal compression system based on frequency transformation and parameter extraction techniques. It uses discrete cosine transform (DCT) and Fast Fourier transform (FFT) to compress the ECG signal. This compressed ECG signal is embedded with corresponding heart rate information in order to obtain a high quality reconstructed signal required for accurate cardiac state diagnosis. The proposed algorithm is tested for compression of bradycardia and tachycardia ECG rhythms selected from MIT-BIH arrhythmia database and the performance is evaluated using compression ratio and percent root-mean-square difference (PRD). The high compression ratio, low reconstruction error and less computational complexity justify the efficiency of hybrid techniques in ECG signal compression and thus, in tele-cardiology.

III. SUMMARY & CONCLUSION OF REVIEW

The examination of the ECG signal has been widely used for diagnosing many cardiac diseases. The researcher has proposed many ECG data compression. This paper provides an overview of various ECG compression techniques along with the limitation. It is found that the frequency transformations techniques better performs than other parameter extraction and direct compression techniques used for ECG compression. Number of frequency transformation techniques including DCT, FFT, DST, DWT, CWT etc. has been utilized by the researchers to perform ECG compression. DWT based techniques are widely used but it may lead to computational complexity and hence may increase response time of the system. This is because wavelet transforms utilize and produce large number of wavelet coefficients. Table 1, shows the performance of different algorithms that were proposed earlier for ECG compression.

TABLE I. COMPARISON ECG TECHNIQUES

Technique	CR	PRD
TP	2:1	28

AZTEC	10:1	5.3
FAN	3.1	4
Fourier Descriptor	7.4:1	7.0
DCT	90.43	0.9382
DST	85.18	1.2589
DCT2	95.77	1.3319

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