Efficient Compression Technique for Electrocardiography Data: Retaining Clinical Salience in Continuous Patient Monitoring

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Abstract: The process of capturing the electrical activity of the heart over a duration using electrodes placed on the skin is referred to as Electrocardiography (ECG). As engage in continuous patient monitoring, managing vast volumes of ECG data becomes imperative. With each monitoring session, considerable data must be stored to assess the patient's cardiac condition. However, the storage, transmission, and allocation of bandwidth for this metadata pose significant cost challenges.

To address this issue, an effective compression technique has been developed to ensure the retention of essential clinical features. This technique optimizes the storage and transmission of ECG data without compromising critical diagnostic information. In this approach, we have implemented a compression method that preserves all salient features necessary for clinical interpretation.

To validate the efficacy of the compression technique, we conducted testing using the MIT-BIH ECG database. This comprehensive database serves as a benchmark for evaluating the performance and accuracy of compression algorithm. Through rigorous testing and analysis, aim to demonstrate the reliability and effectiveness of approach in managing ECG data efficiently while maintaining diagnostic integrity.

Keywords: ECG, MIT-BIH ECG, wavelets –DCT.

I. INTRODUCTION

An electrocardiogram (ECG) serves as a standard diagnostic test to assess the heart's functionality by capturing its electrical activity. Patients with cardiac conditions often require extensive ECG recordings for diagnostic purposes, necessitating substantial storage space. Therefore, there is a growing need for a system capable of compressing ECG signals while facilitating thorough analysis.

ECG compression stands out as a superior technique for reducing computational complexity and storage requirements. Both signal compression and analysis find applications across various fields, particularly in the biomedical domain. Since ECG patterns vary among individuals, ECG pattern recognition emerges as one of the most reliable methods for identifying heart conditions.

The ECG, being the primary tool for cardiovascular monitoring and diagnosis, detects the heart's electrical activity through electrodes attached to the body. These electrodes record and store ECG signals over extended periods. The processing of ECG signals involves extracting waveform parameters such as the P wave, QRS complex, and T wave from existing ECG libraries. Among these parameters, the QRS complex holds particular importance as it reflects the ventricular muscle's electrical depolarization, providing crucial insights for physicians in understanding cardiac conditions.

Patients with a history of heart diseases often maintain extensive records of ECG reports for medical consultations. Our objective is to develop a system that compresses ECG signals to categorize normal and abnormal signal classes efficiently. Digitizing ECG signals resolves storage issues and enhances accessibility for sharing and retrieval purposes.

II. LITERATURESURVEY

Tenedero, M.C.Raya, D.A.M..; Sison, G.L Third National Electronics & Engineering Conference, Phillipines, November 2002–Designand implementation of a single-channel ECG amplifier with DSP post-processing in MATLAB.

This Research paper proposes constructed single-channel ECG amplifier is capable of acquiring a satisfactory reading of rest ECG signal. It can be expanded to be a multi-channel ECG amplifier capable of recording the standard 12-Lead system. For the most accurate and reliable ECG results, site selection and site preparation go hand in hand. Where and how the ECG electrodes are attached greatly affect the sensitivity of the ECG reading. Furthermore, better results are achieved if digital filtering is employed.

Amol R. Madane, Gajanan G. Kale, International Journal of Engineering Research & Technology, Vol.2 - Issue 6, 2013 –Electrocardiography Compression using Fast Fourier Transform.

In this paper, method for compressing ECG signal based on fast Fourier transform has been discussed. The key idea lies in the estimation of QRS-complex signal from a given ECG signal. The QRS-complex is estimated using parameters extracted from the original ECG signal. It results in higher CR with less PRD. FFT technique will require further investigations in order to improve the clinical usefulness of this novel signal processing technique. Simultaneously diagnostic and prognostic significance of wavelet techniques in various fields of electro cardiology needs to be established in large clinical studies.

NidhalK.ElAbbadi and Abbas M AI-Bakry, International Journal of Computer Science Issues,Vol.10, Issue 4, 2013, –New Efficient Technique for Compression of ECG Signal.

This research paper proposes here was essentially no false positive diagnosis made on the entire the uncompressed strips, so itcan be concluded that the compressor which evaluated has no measureable influence on diagnostic specificity. ECG signals that are clean and have a high signal-to-noise ratio (SNR) are relatively easy to interpret, both by a computer and a human healthcare provider. With some improvements to this method can introduce new lossless compression method with high compression ratio. Digital ECG recording and ECG strip offers potentially higher quality.

III. EXISTINGSYSTEM

In previous studies, researchers have proposed various transformation techniques such as Fast Fourier Transform (FFT), Discrete Cosine Transform (DCT), and Discrete Wavelet Transform (DWT) for ECG signal compression. Among these, FFT stands out due to its ability to reduce computational complexity. FFT is commonly applied in ECG signal compression with zero-padding limitations.

The ECG signal decay is often considered time-varying due to certain cardiac abnormalities. By employing standard FFT conditions, Fourier series coefficients are computed for each recognized cycle, which are then used to reconstruct the original signal. The compression and reconstruction phases of the method are illustrated in the block diagram.The initial stage involves the computation of transformations followed by applying threshold conditions to the transformation coefficients based on the energy packing efficiency. This process involves setting a fixed number of threshold values to zero. Various thresholding techniques, such as adaptive, fixed, or manually set thresholds, can be adopted based on the maximum coefficient value.

Subsequently, uniform quantization is applied to these coefficients, where the step size is determined based on the maximum and minimum values of the signal. Quantization levels and corresponding quantization tables are created to reconstruct the original signal. However, the quantized data often contains redundant information, leading to space wastage. To address this drawback, the entropy encoding technique known as Huffman coding is utilized. In this stage, probabilities of symbol occurrences in the signal are calculated to create a new table, which provides the compressed version of the ECG signal. For classification and analysis purposes, the table must retain information regarding the R peak and RR interval. It is evident that the quantized table is directly related to the original ECG signal.

A. Fourier Transform:

The analysis of signals is more effectively carried out in the frequency domain rather than the time domain, as signal characteristics are more pronounced in frequency space. One method to convert or transform signals from time to frequency space is through Fourier transform (FT). FT is a technique that decomposes the signal into various frequencies of sinusoids and is recognized as a fundamental method for signal transformation from time to frequency domain. However, FT has a limitation: it is suitable only for stationary signals, which do not change over time.

The drawback of FT is evident when dealing with non-stationary signals, where signal characteristics vary over time. Since FT is applied to the entire signal and not segments of it, it cannot effectively handle non-stationary signals that exhibit temporal variations. Additionally, another limitation of FT is the inability to determine when a specific event occurred within the signal.

B. Short-Time Fourier Analysis:

In response to the limitations of the Fourier Transform (FT), Dennis Gabor introduced a new technique called windowing in 1946. This method allows for the analysis of small segments of a signal and is known as the Short-Time Fourier Transform (STFT), which provides time and frequency information. In STFT, the window is adjusted to analyze different segments of the signal. Unlike FT, the window in STFT remains constant over time, allowing for both tight resolution and wide resolution. However, it is not possible to predict the frequency content at every time interval segment.

C. Discrete Cosine Transform:

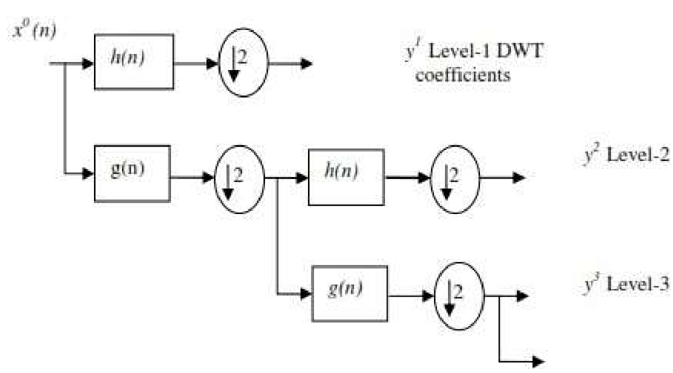
DCT is one of the transformation technique used to decompose the host signal into several frequency bands, which makes a lot easier to do the compression of meta data, where the data can be converted in to spatial domain and will be divided into 8x8 blocks and the 1DDCTis applied to each block respectively. The two dimensional DCT is given by

$$C(u,v) = \frac{1}{2N^3}\sum_{0}^{M-1}\sum_{0}^{N-1} f(x,y) * [\cos(2x+1)\,u\pi * \cos(2y+1)\,v\pi]$$

Wavelet Analysis:

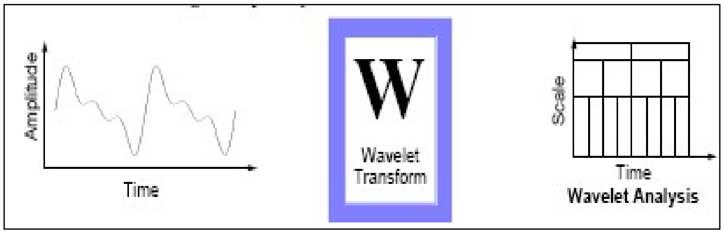
To address the limitations of the Short-Time Fourier Transform (STFT), a wavelet technique known as variable windowing has been introduced. Wavelet analysis enables the utilization of long time intervals to capture precise low-frequency information, as well as shorter regions to capture high-frequency information.

Figure.1. Wavelet Decomposition Tree



The figure above illustrates the decomposition of the input signal using wavelet transform and demonstrates how the transformed analysis is applied to extract frequency information. It reveals a greater number of features, showcasing the effectiveness of wavelet analysis, also known as multi resolution analysis (MRA).

Figure.2. Windowing Technique with Variable Sized Regions



Wavelet analysis represents a significant advancement: a windowing technique with variable-sized regions. This approach permits the utilization of extended time intervals for precise low-frequency information and shorter regions for capturing high-frequency details.

IV. Problem Statement:

In the face of a rising number of heart-related issues, the volume of heartbeat recordings needing storage has become considerable. Storage requirements vary among individuals, posing a significant challenge as the number of heart patients continues to increase.

The process entails recording the current heart condition of an individual and storing the data. Subsequently, the individual undergoes treatment, requiring another assessment of their heart condition and the storage of new data to evaluate the treatment's effectiveness. These steps culminate in data comparison, analysis, and reaching a final conclusion. While this process is for one person, the sheer number of heart patients exacerbates the challenge of storing and managing the data.

Data compression emerges as the sole viable solution. While techniques like Fast Fourier Transform (FFT) and Discrete Fourier Transform (DFT) can compress data, they primarily handle trigonometric functions. Existing ECG compression algorithms rely on simplistic mathematical distortion measures like the percentage RMS difference (PRD) to assess reconstructed signals. However, such measures lack relevance in terms of diagnosis. Furthermore, these measures are not integral to the compression algorithm; they are merely used for evaluating compression outcomes.

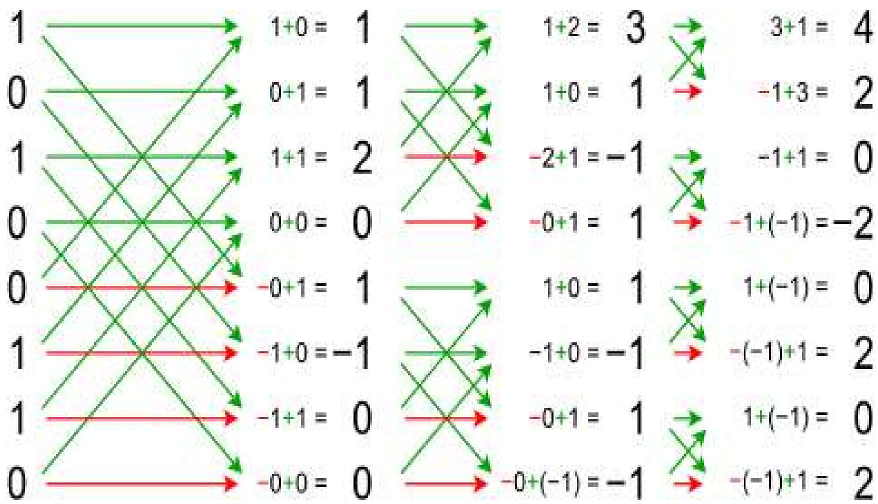
V. Proposed System:

Heart diseases pose a significant concern for many individuals. Therefore, the detection and prevention of heart-related issues are of paramount importance. Electrocardiogram (ECG) monitoring serves as the standard test for identifying heart problems. This project employs a divide and conquer algorithm for the analysis of ECG waveforms.

Patients with heart-related issues often have extensive ECG records for diagnostic purposes, necessitating substantial storage space. ECG compression emerges as a superior technique for minimizing computational complexity and storage requirements.

Hence, an automated diagnosis system is proposed for physicians, particularly cardiologists, to facilitate easy identification of ECG variations and categorization of ECG waveforms into normal and abnormal classes. By incorporating compression and reproduction capabilities into such a system, the issue of memory shortage can also be mitigated.

Figure.3. Example of Fast WHT using DCA



The Discrete Walsh-Hadamard Transform (DWHT) is an orthogonal transformation that dissects a signal into a series of orthogonal, rectangular waveforms known as Walsh functions. The Hadamard transform operates solely on binary values, specifically +1 or -1. The direct and inverse DWHT pair for a signal x(t)x(t) of length NN are respectively expressed as follows:

$$y_n = \frac{1}{N}\sum_{i=0}^{N-1} x_i WAL(n,i)$$

- **Algorithm:**

Step1: Read an input ECG signal_ O‘ from MIT-BIH database.

Step2: Replicate it to create more data_Or‘.

Step3: Add some random noise to the_Or‘ with a variance of 0.1 to get the_X‘.

Step4: Now apply DCA to the_X‘to get the Walsh hadamard coefficients with lesser number of coefficients.

Step5: Consider only first 1024 coefficients out of 4096, which has most of signal energy and store it in ―Y.

Step 6: Now, reconstruct the ECG data using ―Y by applying in verse DCA.
Step7: Finally, compare the_O‘ and _R‘ to observe the compression of ECG data in which the storage memory has been reduced from 32,678bytes to 8200bytes.

VI. RESULT

This paper presents the experimental analysis of the proposed DCA algorithm for compressing ECG signal data conducted in the MATLAB environment. MATLAB is a high-level technical computing language widely utilized for developing signal processing algorithms. It offers numerous advantages over conventional programming languages such as C, C++, Java, Fortran, Cobalt, VHDL, and Verilog. The MIT-BIH ECG database was selected for testing the proposed algorithm.

The original ECG signal data is depicted in Figure.4 The output of the DCA scheme is illustrated in Figure.5., revealing that the majority of the signal energy is concentrated in coefficients less than 1100.

Figure.6. demonstrates the reconstructed signal compared with the original signal after applying the inverse DCA scheme, considering only 1024 coefficients. This observation suggests that the signal is compressed nearly four times compared to the original ECG signal data, resulting in a compression ratio of 4:1.

Figure.4. Input ECG signal

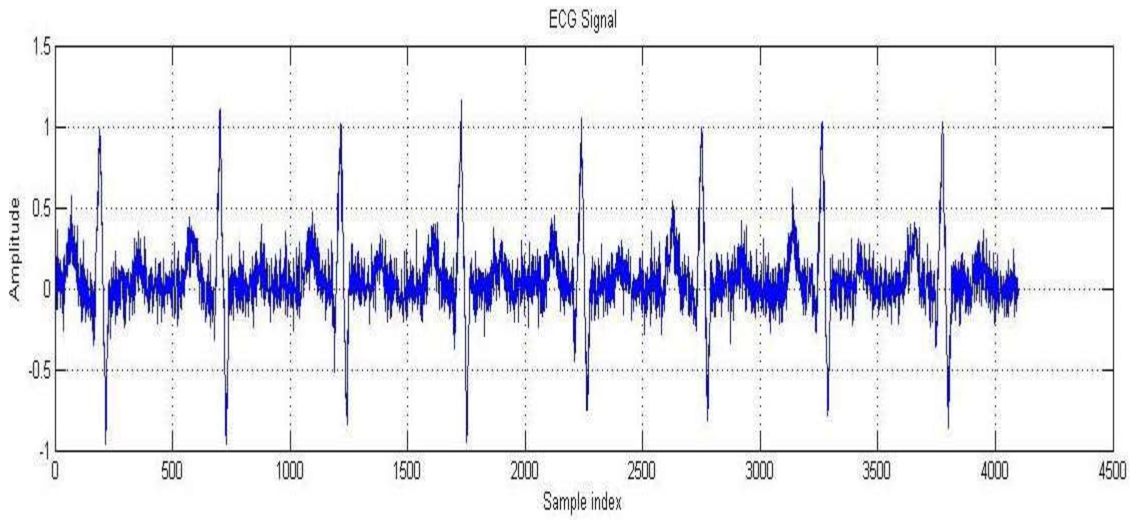


Figure.5. Coefficients after applying DCA scheme

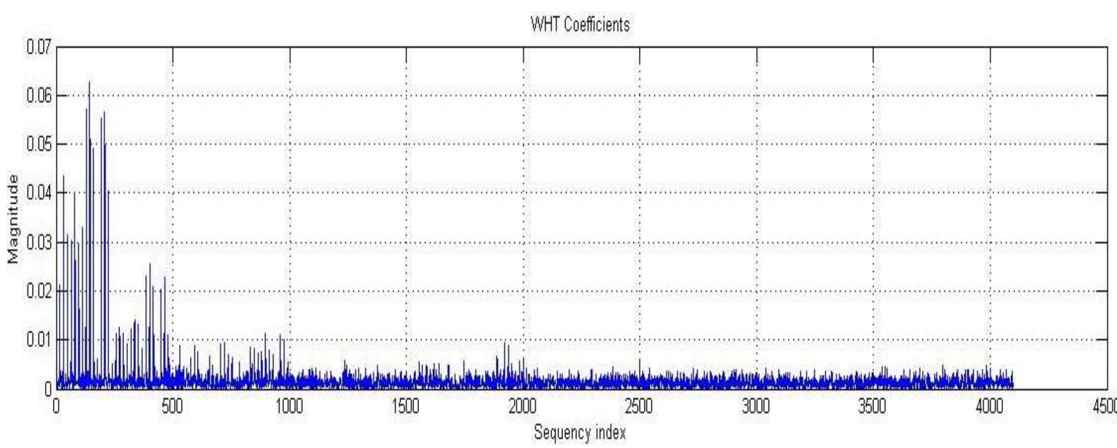
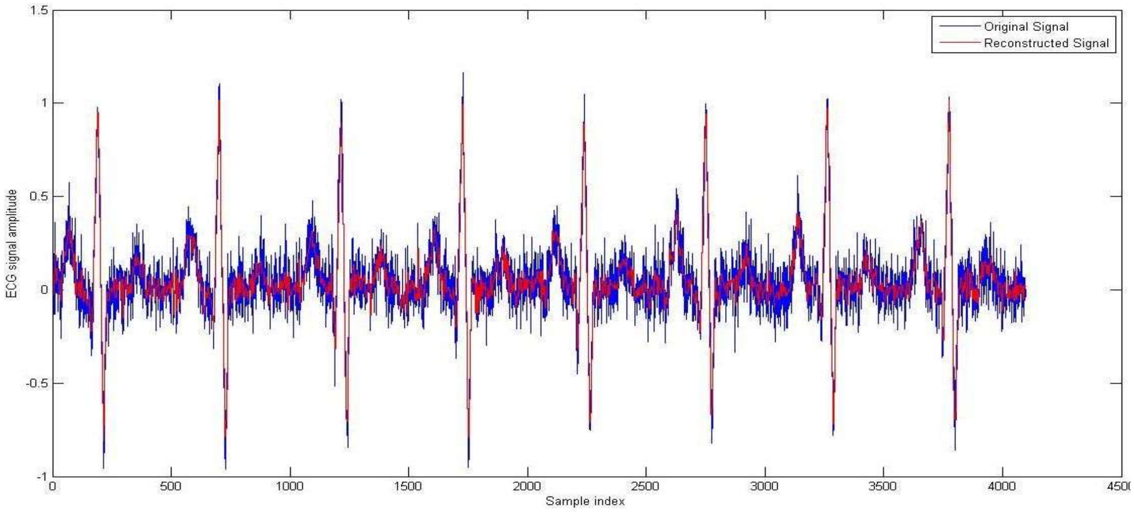


Figure.6. Comparison of original and reconstructed signal using DCA scheme



VariableName	Bytes
X	8200
Y	32768

VII. CONCLUSION & FUTURESCOPE

An efficient compression scheme for electro cardiac signal data has been implemented, utilizing the DCA scheme to reduce computational complexity. The proposed scheme demonstrates superior simulation results compared to conventional compression methods, particularly in terms of storage efficiency measured in bytes. While the combined features of S-transform-based morphological features and temporal features excel in ECG beat classifications, they encounter challenges in accurately classifying certain beats, such as supraventricular (S) and normal (N) classes. Notably, the QRS complex associated with an atrial premature beat of class S often shares similar QRS duration and morphology with class N. Hence, incorporating a complementary feature set could aid in distinguishing between atrial premature and normal beats. An ideal feature transformation technique should render the extracted feature vectors linearly classifiable, possess low dimensions to reduce computational load, and contain decorrelated features.

The considerable variation in normal and abnormal ECG signals among different patients occasionally leads to misclassifications of cardiac disorders. An unsupervised classifier for ECG beat classification emerges as a potential solution, as it does not necessitate prior knowledge of classes or training datasets for classification. Additionally, the analysis of other biosignals like electromyogram (EMG) and electroencephalogram (EEG) is crucial for diagnosing various illnesses. EMG aids in identifying abnormalities in muscles or nerves, while EEG can diagnose neurological conditions such as epilepsy, tumors.Further research avenues include extracting fetal ECG signals from composite maternal ECG signals, which is challenging due to the stronger maternal signal and background noise from muscle activity and fetal motion. Analyzing the extracted fetal ECG signals for automatic detection of cardiac abnormalities presents another area of research interest.

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