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Research article

Heart rate monitoring and therapeutic devices: A wavelet transform based approach for the modeling and classification of congestive heart failure

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ABSTRACT

Heart rate monitoring and therapeutic devices include real-time sensing capabilities reflecting the state of the heart. Current circuitry can be interpreted as a cardiac electrical signal compression algorithm representing the time signal information into a single event description of the cardiac activity. It is observed that some detection techniques developed for ECG signal detection like artificial neural network, genetic algorithm, Hilbert transform, hidden Markov model are some sophisticated algorithms which provide suitable results but their implementation on a silicon chip is very complicated. Due to less complexity and high performance, wavelet transform based approaches are widely used. In this paper, after a thorough analysis of various wavelet transforms, it is found that Biorthogonal wavelet transform is best suited to detect ECG signal's QRS complex. The main steps involved in ECG detection process consist of de-noising and locating different ECG peaks using adaptive slope prediction thresholding. Furthermore, the significant challenges involved in the wireless transmission of ECG data are data conversion and power consumption. As medical regulatory boards demand a lossless compression technique, lossless compression technique with a high bit compression ratio is highly required. Furthermore, in this work, LZMA based ECG data compression technique is proposed. The proposed methodology achieves the highest signal to noise ratio, and lowest root mean square error. Also, the proposed ECG detection technique is capable of distinguishing accurately between healthy, myocardial infarction, congestive heart failure and coronary artery disease patients with a detection accuracy, sensitivity, specificity, and error of 99.92%, 99.94%, 99.92% and 0.0013, respectively. The use of LZMA data compression of ECG data achieves a high compression ratio of 18.84. The advantages and effectiveness of the proposed algorithm are verified by comparing with the existing methods.

1. Introduction

The global increase in the deaths caused by cardiovascular diseases (CVD) is on a rampage and agencies have cited alarming percentages of such deaths [1]. With more hectic lifestyles, rapidly aging population and globally expanding life expectancy, control of CVD require purposeful and consequential healthcare amenities. This increasing problem can be efficiently dealt with the creation of economic, patient-centric and wearable wireless devices for recording and tracking vital signs. Dedicated measures and devices intercepting early signs of CVD can be a better way off in early preventive, diagnostic test models. The big challenge here is to develop self-effacing, humble, patient-friendly wearable device for reading and monitoring electrocardiogram (ECG) data in continual and uninterrupted manner. The next level challenge for such devices is to be light in weight with extended battery life, which requires a substantial integration and simulation of signals and complex data [2].

The wearable portable device thrives and draws power from wireless transceiver. To increase the efficiency of a wearable heart monitoring device, it is much imperative to decrease or prune the use of transceivers, hence efficaciously lowers the power consumption. Analysis of QRS complex detection and R-R interval estimation as part of ECG signals as shown in Fig. 1, are much advisable and advantageous to be conducted for an ECG sensor. Such analysis facilitates and activates the required transmission when it is adjudged to be of critical importance based on patient's cardiac health, thereby leading to decreased power generated through the system. Additionally, the continuous monitoring of patient's heart thus leads and generates a sizeable and substantial amount of ECG data which requires being accumulated and hosted locally in various formats of memory and data storage. Once reserved appropriately, the data needs further seamless transfer to appropriate channels for meaningful investigation. This series of steps in the data collection, storage, and analysis requires heavy power utilization.

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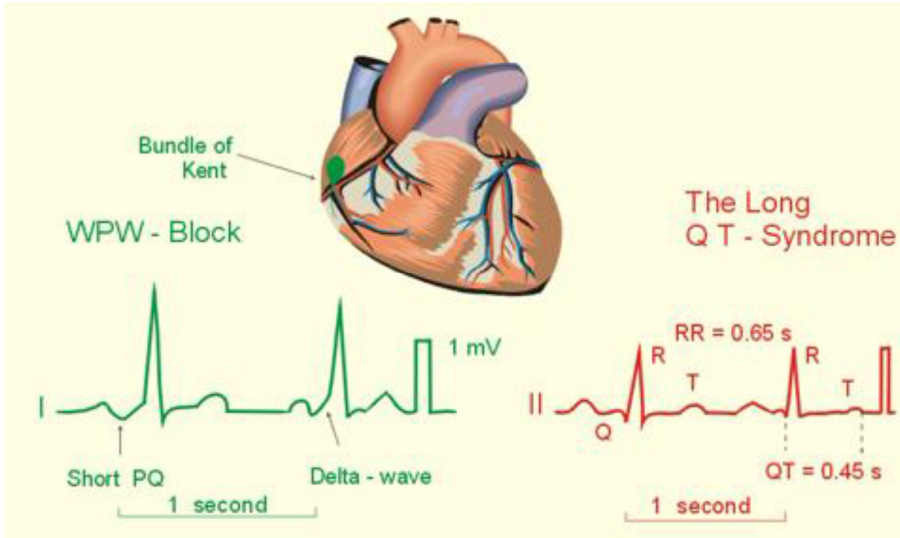

Fig. 1. Graphical representation of a typical ECG signal.

To deal the substantial power requirements of ECG data transmission, efforts are being made to compress the ECG data to minimize the rate at which data is produced for transmission is reduced thus helping in lowering the power requirements of the system. To achieve high compression ratio lossy data compression techniques and procedures are considered, but they have failed to provide required results. The ECG signal reconstructed after lossy data compression results in an ECG signal that contains a sizable amount of noise, due to which crucial diagnostic data gets wasted thus lacking regulatory conformity. For medical applications, the complications in lossy compression techniques used in ECG data compression demand usage of lossless data compression techniques of ECG signals. The world of wearable sensors is experiencing new waves with high-efficiency, decreased power operation and modest convolution in the application. Hence, it is much required to find a better fit and balance between the complexity and compression ratio (CR).

The current trends and medical scenario, have given birth to several QRS complex detection algorithms [3,4,60–62]. The striking feature of all these detections algorithms is reduced power consumption which is an enabler of wearable devices. The research in wearable devices has integrated both unified lossy and lossless data compression techniques together. The research advancements in cardiac health monitoring have made it quantifiable to note the reduction in the sensor power by 2–5 times [5]. It is comprehended that implementation and combination of two distinct hardware setups for QRS complex detection and compression lead to increased system computations and power. Therefore, it is of utmost importance to have a joint QRS complex detection and lossless data compression algorithm.

In the present work, an improved wavelet transform based joint ECG detection, and data compression algorithm applicable for the modeling and characterization of congestive heart failure is proposed. To decide on congestive heart failure, a detailed analysis and characterization of the ECG signal morphology are required. The biorthogonal wavelet transform is used to design wavelet filter banks (WFBs) due to its higher SNR compared to other wavelet transforms and requires less number of coefficients, and its shape resembles the ECG wave. The proposed wavelet filter bank is different from previously designed WFBs. Instead of using conventional low and high pass filter pairs, the proposed decimated WFB architecture consists of a series combination of three lowpass filters realized using wave digital filter realization. The proposed architecture thus considerably reduces the circuit complexity as less number of gates, and less number of clocks with different frequency at each level are required which results in an advantage of lower dynamic power dissipation. Lowpass filters realized using wave digital filter structure reduces the multipliers count by 75% and delay elements count by 80%. In the ECG detection block, an adaptive slope predication-based threshold is employed. Furthermore, Lempel–Ziv–Markov chain algorithm (LZMA) data compression technique is used to compress the ECG data. Finally, the efficiency of the proposed design is quantified regarding signal-to-noise ratio, detection accuracy, percentage root mean square difference and compression ratio.

The rest of the paper is structured as follows. Following the introduction in Section 1, the methodology used to design the proposed work is discussed in Section 2. The detailed description of the results is provided in Section 3, and the results are discussed in detail in Section 4. Finally, Section 5 concludes the paper.

2. Methodology

Different recorded physiologic signals from Massachusetts Institute of Technology-Beth Israel Hospital (MIT-BIH) arrhythmia database, PTB diagnostic ECG database, from physionet.org [6] are chosen for the analysis of the proposed method. The MIT-BIH arrhythmia database contains 48 different ECG signals recorded from different subjects. The duration of each record is 30:06 min with a frequency of 360 Hz. The collected data is further classified into five types: normal, atrial premature contraction (APC), premature ventricular contraction (PVC), left bundle branch block and right bundle branch block. Table 1 categorizes different ECG signals available in MIT-BIH database.

The methodology used to develop the proposed design is elucidated below. Joint ECG detection and data compression algorithms contain three building blocks, namely, pre-processing, peak detection and

Table 1
Detail of different types of ecg signals.

Type of ECG Signal	ECG record	Total number of beats
Healthy	100, 101, 108, 112.	2000
Atrial Premature Contraction	103, 121, 124, 200, 201, 202, 205, 207, 209, 213, 215, 219, 220, 222, 223, 228, 231, 232, 233	2000
Premature Ventricular Contraction	106, 107, 200, 201	2000
Right Bundle Branch Block	118, 207, 212	2000
Left Bundle Branch Block	109, 111, 207, 214	2000