Signal Processing Algorithm for Wireless ECG Monitoring Systems

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Abstract - *The Electrocardiogram (ECG) is a graphical recording of the electrical signals generated by the heart. The signals are generated when the cardiac muscles depolarize in response to electrical impulses generated by the pacemaker. In this work, we propose an efficient method to monitor and classify the ECG signals. The initial task carried out was to eliminate the noise, which involved extracting the required cardiac components by rejecting the background noise. The second task was to perform R peak detection, which was achieved by using the Windowed Short Time Fourier Transform (STFT). The Heart Rate Variability (HRV) was also found by calculating the difference between two simultaneous R-Peaks. The simulations were carried out in the MATLAB environment. The experiments were carried out using data from the MIT-BIH Database. This paper proposes an algorithm to monitor cardiac atrial fibrillation, which is an essential precursor to myocardial infarction.*

Keywords: Short Time Fourier Transform, Atrial Fibrillation, Teager Energy Operator (TEO), Empirical Mode Décomposition, Electrocardiogram

1 Introduction

Bioelectrical signals express the electrical functionality of different organs in the human body. The ECG is an important signal amongst all bioelectrical signals. It reflects the performance and the properties of the human heart and conveys very important hidden information in its structure. This information has to be extracted and analyzed before any useful and meaningful interpretations can be made. Extracting or decoding this information or features from the ECG signal are found to be very helpful in explaining and identifying various pathological conditions. The second phase of this work comprises of extracting the features, which is accomplished in a straightforward manner by analyzing the ECG visually on paper or on screen. [1] However, the complexity and the duration of ECG signals are often quite considerable, making manual analysis a very time-consuming and limited solution. [3]. In addition, manual feature extraction is always proned to errors. Therefore, ECG signal processing has become an indispensable tool for extracting clinically significant information from ECG signals, thereby reducing the subjectivity of manual ECG signal analysis. The proposed system is a Wireless ECG Monitoring System which incorporates a Signal Processing Algorithm for pre-processing and peak-detection of the ECG signal. Being a wireless system, it overcomes the mobility and environment problem. The system also gives out warning signals to the doctor about possible cardio-vascular disorders in patients who could be remotely located. Section II describes the related work. Section III explains the architecture and design of the proposed wireless ECG Monitoring System. Section IV describes the proposed algorithm. Section V describes the algorithm used to extract the features of the ECG using Daubechies 4-tap algorithm. Section VI describes the Implementation and Section VII describes the Conclusion.

2 Related Work

In [1], the authors described the difference between the original and the filtered ECG signal pattern. There was also a study conducted by the authors about the convergence time, the execution time and the relative statistics in time and frequency domain for the ECG signal.

In [2], the authors described how wavelets could be used in combination with Neural Networks to model ECG signal. In this paper the authors make use of the multi-resolution nature of wavelets and the adaptive learning ability of Artificial Neural Networks which is trained by an algorithm that includes the Particle Swarm Optimization (or the PSO).

In [3], the authors describe about foveation which modulates the coefficients of the Discrete Wavelet Transform (DWT) of an ECG record. This process is mainly used to select the major portions of interest in an ECG record by using a mask in the spatial domain. Also, they say foveation can be used for denoising and coefficient quantization.

In [4], the authors described the usage of Hidden Markov models to classify the ECG waveform. The classification is done after the ECG is decomposed into three levels of decomposition using Wavelet Transforms. There are three types of classifications described based on the number of beats. They are Normal (N), Atrial Flutter (AF) which often acts as a precursor to myocardial infarction, and Normal Sinus Rhythm (NSR).

In [5], the authors describe about a technique called Phase-rectified signal averaging which is a method recently introduced in the field of signal processing to process quasiperiodic signals. Herein the authors use this approach to detect Atrial Fibrillation from the surface ECG components. The fibrillation components are highly contaminated ventricular complexes, and the cancellation of these components is never perfect. Hence, this method was adopted to cancel out these artifacts.

In [6], the authors detect the QRS complexes using an operator known as Teager energy operator. This operator operates only on three adjacent samples of the ECG and requires only three arithmetic operations per time shift. This method adopted by the authors gives them 99.9% efficient results for the MIT-BIH database.

In [7], the authors formulate an algorithm for robust QRS onset and offset detection. This algorithm developed was more efficient when tested on MIT-BIH database. The algorithm produced good results for QRS offset and onset detection.

In [8], the authors have proposed an algorithm for ECG signal denoising using Hilbert-Huang transform. The authors use empirical decomposition method to decompose the noisy signal into Intrinsic Mode functions (IMF’s). Spectral analysis was conducted on the successive IMF’s to find out the boundary between the noise dominated IMF’s and ECG signal dominated IMF’s. The authors carry out simulation experiments and claim that this method is more efficient compared to wavelet denoising method.

In [9], the authors use EMD method to decompose an ECG signal. Hilbert transform was used for spectral analysis. The authors claim that decomposing the signal into IMF’s is more suitable compared to wavelet denoising methods.

In [10], the authors use an approach to detect the pacemaker pulses from the ECG. In order to realize this they proposed a fully digital approach that uses a two step filtering strategy which was then followed by a thresholding mechanism. The results obtained after the simulations were carried out were very significant and they claim that it outperforms all the results that were obtained from a well known patented algorithm.

3 Architecture and design

The top overall architecture of the proposed system in depicted in Figure 1. The proposed system has a two tier architecture.

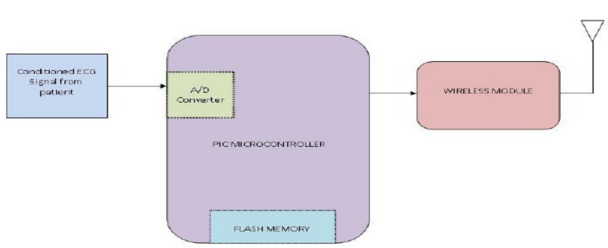

Fig 1 : ECG Transmitting Unit

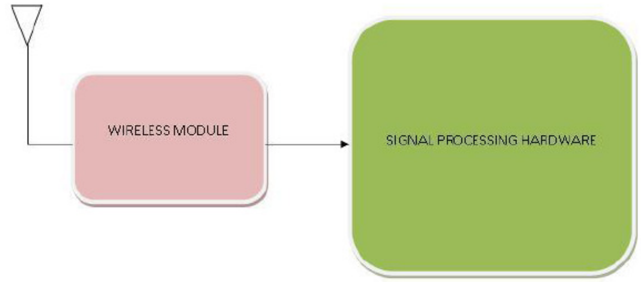

Fig 2 : ECG Receiving Unit

3.1 ECG Acquisition and Transmission Unit (EcgATU)

EcgATU is the module that has an interface with the patient. This module acquires the ECG signal from the patient, performs basic signal processing operations and wirelessly transmits to the ECG Receiving Unit otherwise known as (EcgRU).

The EcgATU and EcgRU are the two modules shown above. The conditioned ECG signal was extracted from the patient. It was then given as an input to the ADC of the microcontroller to obtain its digital equivalent. The microcontroller used was placed on the NI-ELVIS MX kit. The specification of the PIC used in this context was PIC16F877A which is a 32-bit pin microcontroller. The program was loaded onto the PIC using a software known as WINPIC-800.The language used in this context was Embedded C. Since the language used was Embedded C, we are intentionally converting it to an embedded microcontroller.

3.2 Procedure adopted to detect R-Peaks

The ECG signal we have is uneven, thus our first step is to straighten it. To say in mathematical language, we should remove the low frequency component. To achieve this we applied Fast Fourier Transform (FFT), which restores the low frequency components and restores the ECG with the help of Inverse Fast Fourier Transform (IFFT). In the next step, we found out the local maxima, we achieved this using the windowed filter; that sees only the maximum in its window and ignores all the other values. Window of default size was used in this case. Next step is to remove all small values and preserve the significant ones. For this purpose, we used a threshold filter. In this case, the result is good in general case. But we can’t be sure that we have all the peaks. So the next step is to adjust the filter window size and repeat filtering. It is only after performing these operations we obtain the result. The signal processing algorithm used incorporates Short Time Fourier Transform (STFT) for spectral analysis. Below the continuous and discrete time versions of the Fourier Transform are shown in (1) and (2) [7].The block diagram for the spectral detection is as shown below:

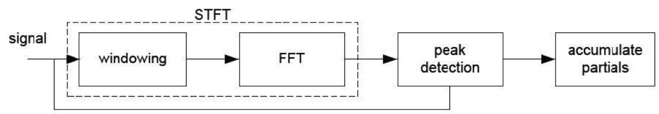

Fig 3 : Block diagram for STFT and Spectral Detection

$$X(\omega) = \int x(t)e(-j\omega t)dt \quad (1)$$

$$X[n] = \sum x[n]e(-jk2\pi n/N) \quad (2)$$

3.3 Heart rate calculator

Heart rate in general, can be calculated using several time domain and frequency domain methods. In our analysis, we used a signal length of N=64 for computing the heart rate.

The formula used to compute the Heart Rate Variability is as follows:

$$PNN25 = (NN25)/(N - 1)*100 \quad (3)$$

Where, PNN25 is the ratio of the number of successive difference of intervals which differ by more than 25ms to the total number of all RR intervals.

4 Proposed algorithm

Condition 1: The algorithm proposed here checks for the normal and abnormal functioning of the heart. It does this by accepting an ECG signal as an input signal. The time interval of the ECG signal is checked for assertion case i.e. width of the signal should be between 0.023s and 0.1s, if the above condition validates, then R-R interval is estimated to be between 0.6 and 1.1s.If these two conditions satisfy, then we can say that the person is not suffering from any cardiac disorder.

Condition 2: If the width of the signal is less than 0.023s and R-R is estimated to be greater than 1.1s, then too we can say that the person is not for any cardiac disorder.

Condition 3: If condition1 and 2 do not validate, then we can corroborate that the heart is functioning in an abnormal manner.

Condition 4: If none of these conditions satisfy, then we perform the iteration from the beginning.[6]

The detection algorithm can further be elaborated by checking for Rough Peaks in the ECG signal. The method to be adopted is to first check for positive and negative slope threshold values to assist in the selection process.

The following conditions should help in detecting the abnormal R-Peaks:[7-9]

1. The slope must change polarity i.e., from positive to negative.
2. The magnitude difference between the peak candidate and the current bin's magnitude component must exceed the threshold component.
3. A new peak candidate search occurs only after there is a slope change from negative to positive, and when a threshold value is exceeds the normal threshold.

Next, we can look for prominent peaks following the Rough-Peak search method, it can be done in the following manner:

1. The R-Peak with the maximum value is found.
2. Relative to position of the R-Peak with maximum amplitude, peaks are analyzed moving towards the iso-electric line.
3. Local maxima or R-Peaks are picked out using an adaptive threshold value that is reflective of all prominent R-Peaks and neighboring R-Peaks.

The flowchart of the algorithm is as shown in Figure 4.

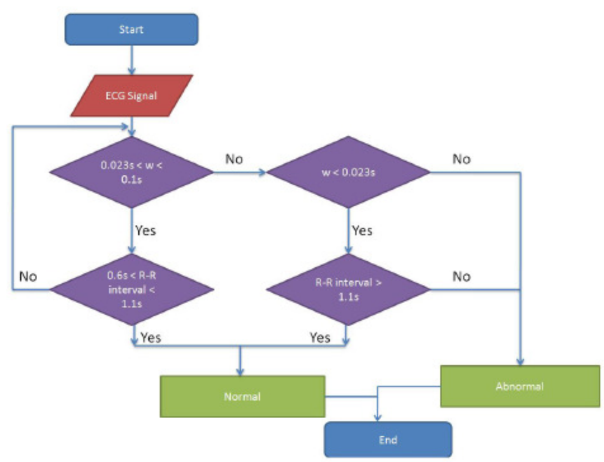

Fig 4 : Flowchart for atrial fibrillation

5 Implementation

As a first phase to the development and implementation of the system, the ECG sample signals were obtained from the MIT-BIH Database and was further used as mat files. These mat files were used as input signals to the developed algorithm.

The algorithm developed was for ECG-R peak detection in MATLAB environment. Two mat files were used and a comparison was drawn between two subjects for finding out the Heart Rate Variability (HRV).The results obtained are as shown for subject 1 and subject2.The HRV obtained for the

two samples were 52.13 bpm and 56.24 bpm respectively.

Also, a Java Data Base Connectivity (JDBC) program was written to read the values of the ECG signal from the database which was subsequently plotted. The results indicated that the R-peaks exceeded the normal threshold.

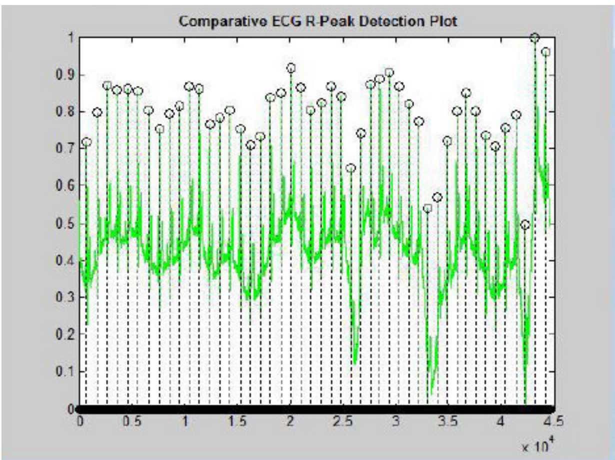

Fig 5 : Comparative R-Peak detection for Sample 1

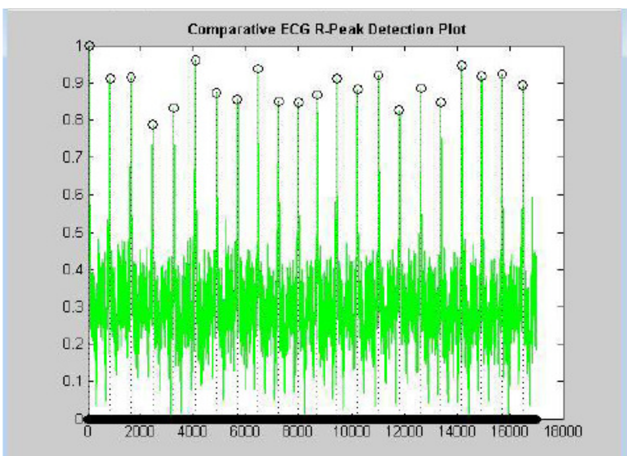

Fig 6 : Comparative R-Peak detection for Sample 2

6 Conclusion

This paper proposes a design for monitoring and detection of the ECG. The main advantage of this system is that remote monitoring and diagnosis is made easier. The system can further be enhanced in performing feature extraction and classification using neural networks. Also, it provides good feasibilty and good performance if the objective is to analyze and interpret the ECG in an efficient manner. The algorithm proposed in this paper for atrial fibrillation is less complex compared to the algorithms previously proposed. It reduces the complexity from $O(n^2)$ to O(nlogn).

7 References

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