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DIAGNOSIS OF CARDIAC DISEASES USING ECG FOR WEARABLE DEVICES

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***Abstract*—Cardiovascular diseases are clinically diagnosed by ElectroCardioGram analysis. By determining the pattern, structure and interval of ECG signal, the cardiac diseases are found. The main cause for this study is to analyse the ECG signal and extract the QRS complex from noise using low computational filters. The approach is promoted for wearable devices so that the size and the cost is very less and may also be used in battery operated devices. The setup is experimented with a prototype of ECG analyser made of a novel filter and implemented in hardware using ARM microcontroller. The filter is designed in MATLAB.**

***Index Terms*—Arrhythmia disease, ARM Microcontroller, ECG analysis, High pass non-linear filter, MATLAB.**

I. INTRODUCTION

The diseases of heart or blood vessels are generally known as cardiovascular disease (CVD). It is a big health problem. The study says that in 2011, there were almost 160,000 deaths as a result of CVD. Around 74,000 of these deaths were caused by coronary heart disease. Most deaths from heart disease are caused by heart attacks. In the UK, there are about 103,000 heart attacks, 152,000 strokes in each year, resulting in more than 41,000 deaths [7]. This disease can be discovered using ECG analysis. An ECG is the electrocardiogram which is a test that measures the electrical activity of the heart. The electrical impulses are generated due to the heartbeat are recorded and usually shown on a piece of paper. This is referred as an electrocardiogram, and records if any problems with the heart's rhythm, and the conduction of the heart beat through the heart which may be affected by underlying heart disease. It consists of five waves namely P, QRS and T. The normal ECG wave is explained in fig.1. Each wave occurs due to some electrical variations in the heart. QRS complex represents the depolarization of the ventricles of the heart which have greater muscle mass and therefore its process consumes more electrical activity.

The applications of ECG are to determine the electric axis of the heart, Heart rate monitoring Arrhythmias, Carditis, Pacemaker monitoring [11]. The automatic detection of QRS is critical for reliable Heart Rate Variability (HRV) analysis, which is recognized as an effective tool for diagnosing cardiac arrhythmias, understanding the autonomic regulation of the cardiovascular system during sleep and hypertension, detecting breath disorder like Obstructive Sleep Apnea Syndrome, and monitoring other structural or functional cardiac disorders. The detection of QRS complexes have been extensively investigated in the last two decades. Many attempts have been made to find a satisfying universal solution for QRS complex detection. The difficulties arise mainly because of the huge diversity of the QRS complex waveforms, abnormalities, low signal-to-noise ratio (SNR) and the artefacts accompanying the ECG signals as described in [8]. The main aim of this work is to increase the accuracy of QRS detection in Arrhythmia ECG signals that suffer from non-stationary random effects, low signal-to-noise ratio (SNR), negative QRS, and low-amplitude QRS.

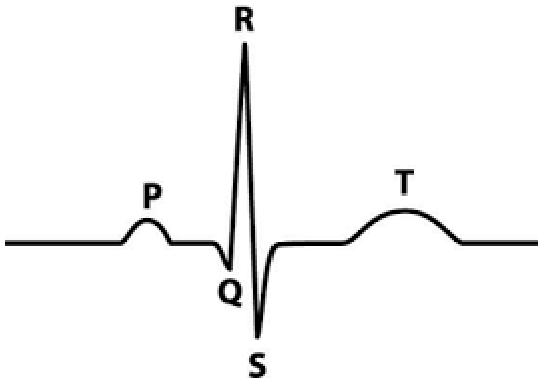

Fig.1 Basic ECG Wave

There are many methods proposed to intent the QRS complexes. But it have more hardware complexity and the cost is high. If the cost is less, then the accuracy will be low [9]. Thus, the proposed technique is to implement with the MIT-BIH database as described by [15] in the hardware with less complexity and less cost. This can be done using ARM microcontroller, so that the response of ECG signal will be fast. A novel filter is designed to eliminate the noise in QRS complex and the accuracy of the signal is increased. This concept will be more useful in wearable devices [1], portable devices and in battery operated devices.

II. COMPARISON OF OTHER METHODS

The acquisition of ECG is a two-step process. (1) Feature extraction (2) Detection. In 1st step, QRS complexes are enhanced and noise in it are removed. This process is done by using different types of band pass filtering. The low frequency noise removal is done by high pass FIR filtering technique [2]. It consists of low cutoff frequencies with numerous taps. Therefore to compute each sample, these filters require n fixed point adders and multipliers. This setup increases the operation complexity to 2.n. If IIR filters are used then floating point coefficients are needed. In 2nd step, the position of QRS complexes is determined by differentiation and squaring of signal. In some methods integration are also used to detect the signal.

Pan and Tompkins is the ancient algorithm [3] for the real time QRS Detection algorithm based on analysis of the slope, amplitude and width of QRS complexes. This algorithm includes series of filters and methods that perform low pass, high pass, derivative, squaring, integration, adaptive thresholding. In recent times, there are many research work have been narrated in automatic detection of QRS complex from ECG signal. Some of them are frequency based methods, time component analysis, dynamic thresholds [5], heart beat interval techniques. These methods are executed using fourier transform or Hilbert transform [6]. It is limited to stationary signals. To overcome this, short fourier transform is introduced.it gives both frequency and time domain analysis. But some signal cannot be detected using STFT [13]. Wavelet transform methods [4] & [14] are developed and among other methods it produces reasonable results, the hardware complexity and cost is high. Though for accurate measurements it is used along with Artificial Neural Network (ANN), multi-layer perceptron based neural network (MLPNN).

III. PROPOSED SYSTEM

A novel algorithm is proposed to apply over real time ECG signals. It is flexible, upgradeable, operates in low processing power and also inexpensive. As similar proposals, it also have enhancement phase followed by detection phase. The computational costs for the first phase are high in other proposals. But the proposed technique is to reduce these costs and avail for the wearable applications. The block diagram for the proposed system is shown in fig.2.

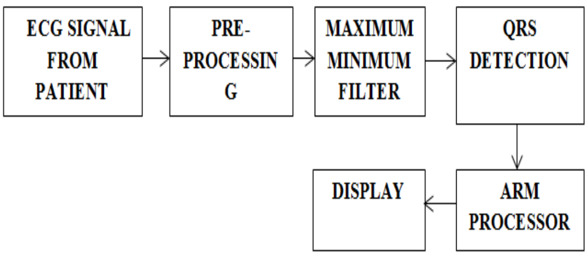

Fig.2 Block diagram

A ECG SIGNAL

The real time ECG signal from the patient is taken for the diagnosis of any cardiac diseases. This signal consists of P, QRS and T waves. In which the proposed algorithm will concentrate on QRS detection. Since it is difficult to determine and it is responsible for the diagnosis of arrhythmia.

B PRE-PROCESSING

The ECG signals have various kinds of unwanted noise due to power line interference, electromagnetic noise and baseline wandering in the heartbeat signal as similar to [12]. So the accuracy of the signal will be degraded, if the signal is acquired in the same way. For this purpose, the pre-processing is needed. The process constitutes passing the raw ECG signal through a low pass filter. It performs both linear and nonlinear filtering of the ECG signal and produces a set of periodic vectors which describe the events. Thus after filtering, the signal is allowed to amplify using amplifier. This will help in feature extraction of the peaks.

C LOW FREQUENCY NOISE REDUCTION

A novel high pass filter is designed with low computational costs to remove the base wander. A high pass non-linear filter is designed. The operation of the filter is to subtract a low-pass filtered signal from the original signal to attain the higher frequency signal. This subtraction is carried out between maximum and minimum values of the signal. Let s(t) be the discrete time function of the digitized ECG signal, then the filtered output y(t) is given by Equation (1), (2) & (3).

$$y(t) = s(t) - \frac{high^*(t) + low^*(t)}{2} \qquad (1)$$

$$high^*(t) = \begin{cases} s(t) & \text{if } t = 0 \\ high^*(t-1) + \sigma.\Delta & \text{if } s(t) \succ high^*(t-1) \\ high^*(t-1) - \Delta & \text{if } s(t) \leq high^*(t-1) \end{cases} \qquad (2)$$

$$low^*(t) = \begin{cases} s(t) & \text{if } t = 0 \\ low^*(t-1) - \sigma.\Delta & \text{if } s(t) \prec low^*(t-1) \\ low^*(t-1) + \Delta & \text{if } s(t) \geq low^*(t-1) \end{cases} \qquad (3)$$

Normally to find s(t) over a window of n samples, n comparisons for each sample is needed, and the amount of computation is increased. To avoid this pseudo-extrema functions is used. It is termed as high* and low* and defined in Eqs. (2) and (3) respectively. The operation of the high*(t) is as follows: a variable with the current maximum is fixed, if the value of the input signal s(t) is equal or lower than the current maximum, it is decreased the current by a factor Δ. If s(t) is higher, then the current maximum is increased by a factor σ·Δ. Low*(t) is defined similarly. By this process heart beats appear as pulses of approximately 1 mV. Therefore the normal heart beats range lies around 60-100 units in the digitized signal. Beats >100 beats/min are termed as Tachycardia as well as <60 beats/min are termed as Bradycardia.

To make the filter smooth, the value of σ is increased so that the cutoff frequency is also increased. Transient dynamics in non-linear filters are not captured by frequency response analysis. By trial and error method, the suitable values for σ and Δ are found.

D HIGH FREQUENCY NOISE REMOVAL

The high* and low* functions are also used to sense amplitude of high frequency signal. To sense the amplitude of the signal the function called m(t) is used. It is defined in the equation (4) as

$$m(t) = high^*(t) - low^*(t) \qquad (4)$$

This m(t) represents the noise factor and it should be subtracted from the signal. Thus the filtered signal with the noise reduction is given by the equation (5). The duration of the QRS pulse is normally in the range of 0.06-0.12s. Therefore some effects are made to improve their detection.

$$r(t) = \begin{cases} sign\left(y(t).\left(\left|y(t)\right| - m(t)\right) \text{ if } m(t) \le \left|y(t)\right|\right) \\ 0 \qquad \text{otherwise} \end{cases} \quad (5)$$

E PEAK DETECTION

All the samples from r(t) is not useful to detect the QRS complexes. The R peaks in this complex will come as positive and negative values. From this the potential R peaks can be filtered. A certain time period is set to filter these peaks. The advantage of this method is that it supports situations were the maximum value remains constant for several samples. The maximum and minimum value of time period is defined by the equation (6) & (7). Thus, this value is considered as peak.

$$a(t) = \begin{cases} r(t) \text{ if } \exists i \succ 0 \left| r(t-i) \prec r(t) \succ r(t+1) \right. \\ 0 \quad \text{otherwise} \end{cases} \quad (6)$$

$$b(t) = \begin{cases} r(t) \text{ if } \exists i \succ 0 \left| r(t-i) \succ r(t) \prec r(t+1) \right. \\ 0 \quad \text{otherwise} \end{cases} \quad (7)$$

F BEAT UNIFICATION

As already discussed that QRS complexes are both in positive or negative peaks. So, the negative peaks are discarded or it can be unified by changing the sign of negative peaks to become positive peaks. This makes useful for fixing the threshold value in the detection step. Normally in other methods it is done by squaring the signal. But the aim of the proposed technique is to reduce the multiplication operation as it requires a higher cost than adding or subtracting. Thus the beat unification time function is defined to reduce the cost is given by Equation. (8).

$$w(t) = \begin{cases} a(t) \quad \text{if } a(t) \succ 0 \\ -b(t) \text{ if } b(t) \succ 0 \end{cases} \quad (8)$$

G BEAT DETECTION

The peaks of w(t) higher than the threshold are considered as heart beats. Their amplitude are measured in the range of mV. In some cases, this amplitude may be varied due to the enhancement process. Therefore, most QRS detection algorithms use an adaptive threshold technique which is used to detect the pulses and to modify the threshold accordingly. In the proposed algorithm to an adaptive threshold is used. Peaks below that threshold are considered as “noise”. The width of the QRS complex is advised as constant. The general fact that the heart rate does not vary very significantly from beat to beat. There are certain criteria are designed to detect the peaks as follows.

Criteria 1

A peak higher than the threshold is considered as detectable heartbeat. Lower peaks are eliminated as noise. The mean of the last 5detected beats are adaptively updated as threshold.

Criteria 2

QRS pulses are lasts from 0.06 to 0.12 s wide. If a peak is detected and if another higher peak is detected inside this time period, the higher peak is examined as a valid heartbeat, and discarding the previous peak.

Criteria 3

The normal heart rate is around 220 beats per minute. It is impossible for another beat to occur before 0.27 s after the detection of QRS complex. Peaks detected after the maximum QRS width and before this period are considered as noise.

Criteria 4

If noise was detected from the last pulse, then consider that beat as noise if the beat is smaller than the maximum noise peak plus the threshold, or smaller than the last detected beat minus the threshold.

1) FLOW CHART OF THE PROPOSED ALGORITHM

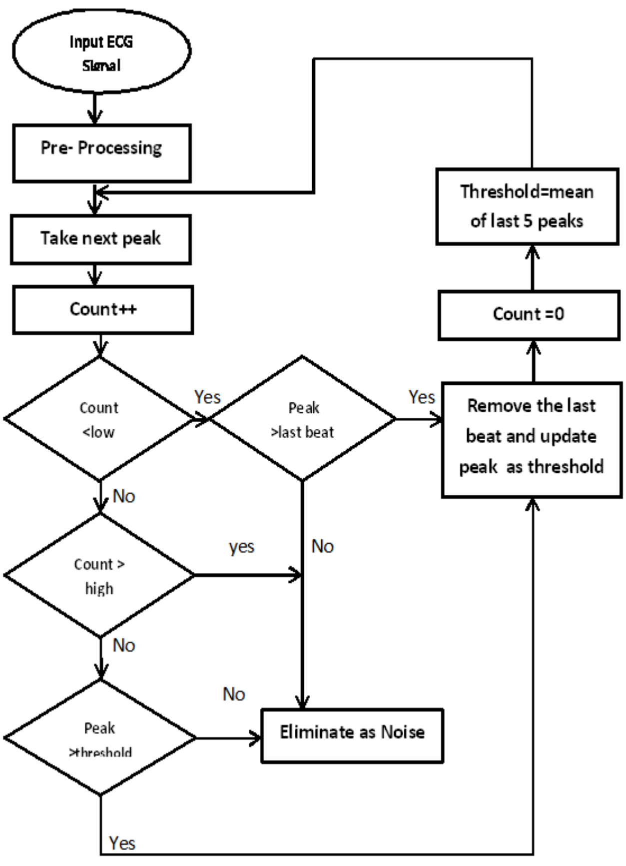

Fig. 3 Flow diagram for proposed algorithm

The Fig 3 represents the step by step process of the proposed method. The ECG signal is obtained from the patient using a single lead sensor. After acquiring the ECG signal, the preprocessing steps such as amplification, noise reduction is done by embedded controller. A certain time period is kept as count and it is allowed to increment. The next step is to calculate the threshold value by taking the average of five peaks of ECG signal. By keeping this threshold value, the next peaks are compared. The peaks below the current threshold value are considered as noise. If any peak greater than threshold will appear, then it will update that peak as the threshold value else, it will eliminate the peak as a noise.

Finally, under periodic intervals the final peak above the threshold value is considered as the desired peak which is used to find the cardiac diseases. By using this peak values, the heart rate of the patient is determined. This heart rate will gives us the information about the state of heart of the patient. After updating the peak value again the process gets continued by, taking the next five peaks to calculate the threshold value so that the final peak can be determined using the algorithm.

2) ARM PROCESSOR

The ARM processor offers five stages pipe lining. The instruction latency is 2.5 ns. The instruction throughput is of 400 MIPS. For wearable sensors, the power consumption must be low. The existing few algorithms are highly computational, so it requires high power. By reducing the duty cycle, the energy consumption is reduced. Due to less interrupt latency, the response will be high. Therefore it is used for the real time processing of the ECG signal.

The ARM9 board which consists of Samsung S3C2440 processor, 32-bit data bus, 5 V regulated supply is used for the implementation of proposed methodology for beat classification in real time.

3) EXPERIMENTAL RESULTS

MATLAB is a multi-paradigm numerical computing environment and fourth-generation programming language. And Simulink, developed by Math Works, is a graphical programming environment for modelling, simulating and analyzing multi domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in automatic control and digital signal processing for multi domain simulation and Model-Based Design.

$$Sensitivity(\%) = \frac{True\ Positive}{True\ positive + False\ Negative}$$

$$Positive\ Prediction\ (\%) = \frac{True\ Positive}{True\ Positive + False\ positive}$$

$$Detection\ Error(\%) = \frac{False\ Positive + False\ Negative}{Total\ QRS}$$

The heartbeat is evaluated using the parameters namely sensitivity, positive detection and detection error. Sensitivity is the detection of accurate events among total number of events. Positive detection is the rate of correctly classified events in all detected events. To evaluate these parameters true positive, false positive, false negative are used. A true positive happens when a beat is correctly detected for a certain instant. A false positive happens when a beat has been detected in a certain instant, but no beat has been annotated in the database for that instant. A false negative happens when the database reports a beat for a certain instant but the algorithm fails to detect it.

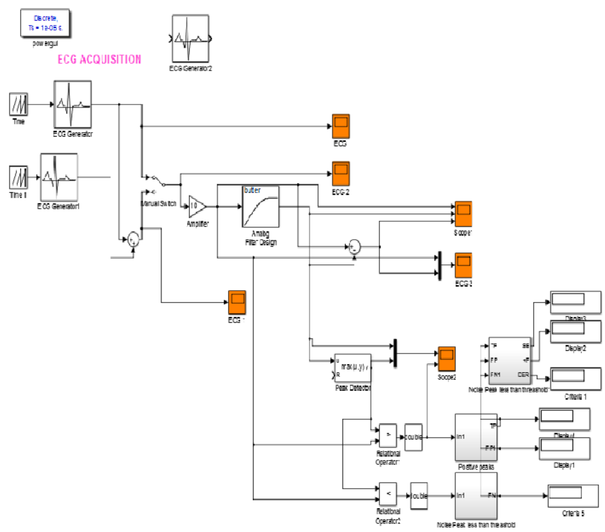

Fig.4 Simulation Block Diagram

The simulation of the proposed filter is shown in the fig 4 is the extension of [10]. It is drawn in MATLAB SIMULINK and ran through the same software to display the results. The entire circuit shows the ECG wave acquisition, amplification, noise reduction using high pass filter and the mathematical calculation of parameters to measure the heart rate are represented.

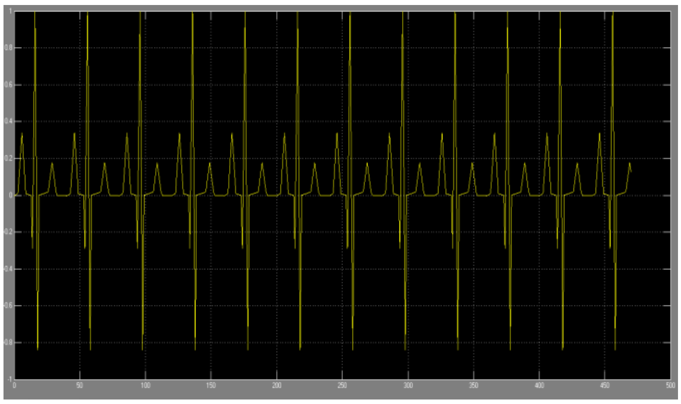

Fig.5 Original ECG Signal

The fig.5 displays the normal ECG signal which is generated using simulink block to determine the peak of the signal. Normally, the ECG signal contains some low frequency noise. So this signal is given to the filter.

Another ECG signal with more noise is generated to analyse the performance of the filter. It is used to compare the accuracy of the normal state of heart rate to abnormal state. This signal is shown in the Fig.6.

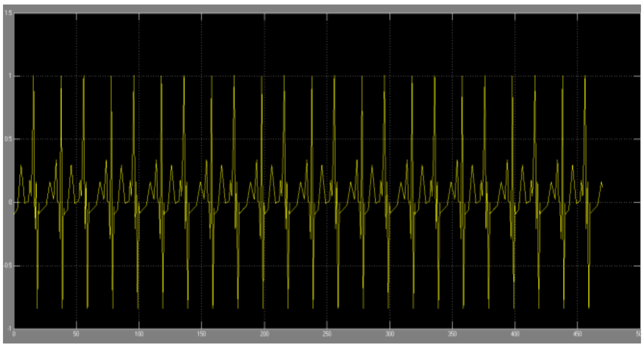

Fig.6 ECG signal with Noise

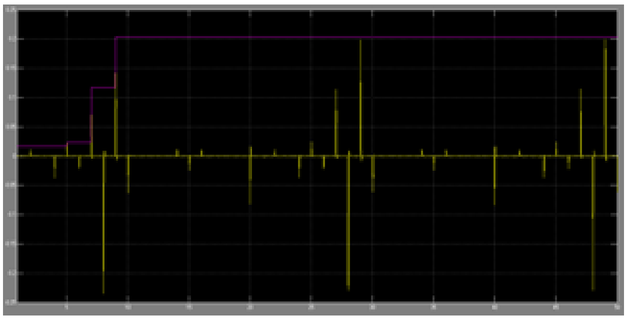

Fig.7 Peak Detection

The peak is calculated based on the algorithm. The Fig.7 represents the peak calculation. The result shows the peaks compared with the adaptive threshold. Only the peaks with the threshold value are shown. Other peaks are eliminated as noise.

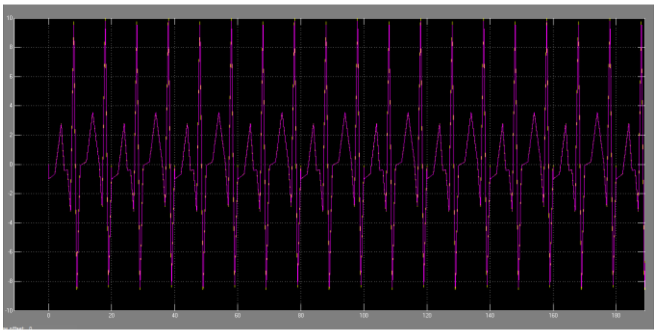

Fig. 8 The final peak from the proposed filter

The final simulation result of the proposed alogorithm with the detected peaks are shown in the Figure 6.6. The performance of the results obtained was better than the existing methods.

IV. COMPARISON OF METHODS:

The method was compared with other existing methods is shown in the Table1. The accuracy of the proposed method is higher the existing method. Thus, the low frequency noise is reduced in this work.

V. CONCLUSION

A non-linear high pass filter called a Maximum Minimum filter, is proposed to remove the low frequency noise and to detect the peak of QRS complex. Thus a simple QRS detector

METHODS	**ACCURACY**
PCA+ANN+PSO	95.5%
RR-INTERNAL+ANN	90%
DWT+ANN	97.93%
PROPOSED TECHNIQUE	98.61%

Table 1. Comparison with Various Methods

The low frequency noise is reduced by using high pass filter. This facilitates in the real time processing of ECG signals with low computational complexity which is useful for portable devices, wearable devices and ultra-low power chips. The proposed filter results 98.61% of efficiency. To determine the heart rate, the parameters were calculated. The result gives 71 beats per minute of heart rate which is the normal heart rate.

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