# Design of an Effective Algorithm for ECG QRS Detection using VHDL

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**Abstract:** *ECG (Electrocardiogram) is said to be a golden tool for diagnosis of various heart related diseases, it is considered as a standard for heart rate monitoring.QRS complex is the most striking feature within the ECG. Great clinical information can be derived from its features. Identification of these features in ECG is known as QRS detection, but ECG signals are easily contaminated with noise and artifacts which make it difficult to analyze with naked eyes so feature extraction becomes complex. Therefore here we developed a QRS complex detector so that physicians can spend more time in diagnosing and treating the patient rather than deciphering these signals. In this system real time ECG signal is taken as an input and baseline wondering and background noise are removed from original ECG signal using linear and non-linear filters. The ECG QRS complex detectors design is simulated using modelsim simulator.*

**Keywords:** ECG, QRS complex, baseline wondering and background noise, Modelsim Simulator.

## 1. Introduction

An Electrocardiogram is a test that measures electrical activity of heart In an ECG test, the electrical impulses made while the heart is beating are recorded and usually shown on a piece of paper. The characteristic wave of an ECG consists of P wave, QRS Complex and T wave.
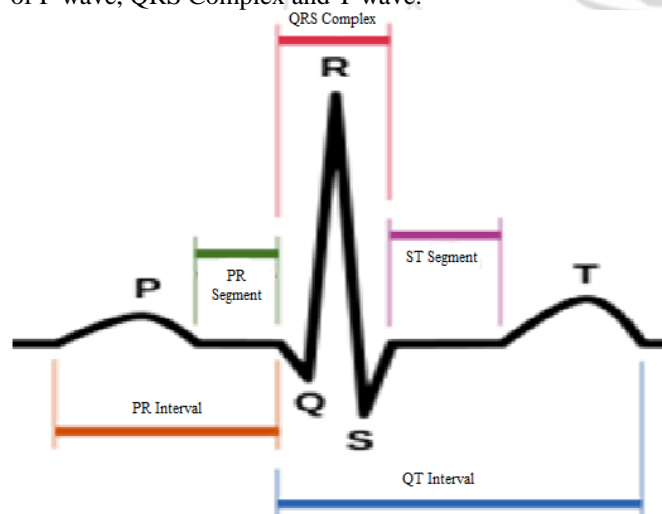


**Figure 1:** Schematic representation of ECG signal.

QRS is the most important parameter in an ECG signal.
Once the QRS complex has been identified a more detailed examination of ECG signal including the heart rate, the ST segment etc. can be performed since the accuracy of instantaneous heart period estimation relies on the performance of QRS detection. The QRS detection should be accurate. On the other hand, it is acknowledged that QRS complex is varying with the physical variations and also affected by noise as time evolves. Therefore, seeking for a reliable QRS detection algorithm is essential to the realization of automatic ECG diagnosis.

The QRS detection is a research topic since last 40 years and numerous approaches to QRS detection have been proposed previously. These approaches vary from use of Artificial Neural Network, Genetic algorithms, wavelet transforms. some algorithms were based on template matching in which algorithms employ a specific QRS template, which might be considered the best way to prevent the QRS detection performance from being degraded by the undesired noise sources contributed from: (1) baseline drifts, (2) artifacts due to electrode motion or power-line interference, and (3) other ECG components with similar morphologies to the QRS complex, such as P and T waves. However, since the template-matching technique involves intensive cross correlation-based similarity measurement between the QRS template and a number of windowed ECG segments, such a heavy computational burden might somehow undesirably restrict its use to only a limited number of aspects .The basic structure of QRS detection is as shown in below figure.
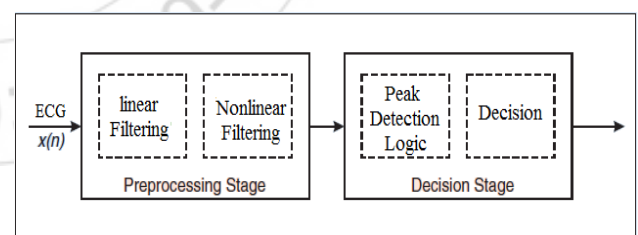


**Figure 2:** Basic structure for QRS detector

Most of the algorithm differ from each other in the way the processing is carried out .In preprocessing stage ECG signal is passed through a number of filtering stages in order to overcome the effect of these unwanted signals which could otherwise lead to false peak detection. The decision stage is heuristic and is dependent on the output of preprocessing stage. The QRS detection algorithm introduced by Pan and Tompkins [1] is the most widely used and often cited algorithm for the extraction of QRS complexes from electrocardiograms. The algorithm presented in this paper consists of linear filters connected one after another in a sequence. The nonlinear part is signal amplitude squaring block. Adaptive threshold and blanking were used as a part

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of decision rule. The methodology followed is that the ECG is passed through a low-pass and a high-pass filter in order to remove noise from the signal. Then the filtered signal is passed through derivative, squaring and moving Window integration phases. Finally, a thresholding technique is applied and the R-peaks are detected.

The main advantage of this algorithm is the use of integer arithmetic in carrying out the processing. The coefficients of filters used in algorithm were all integers and mostly powers of 2.
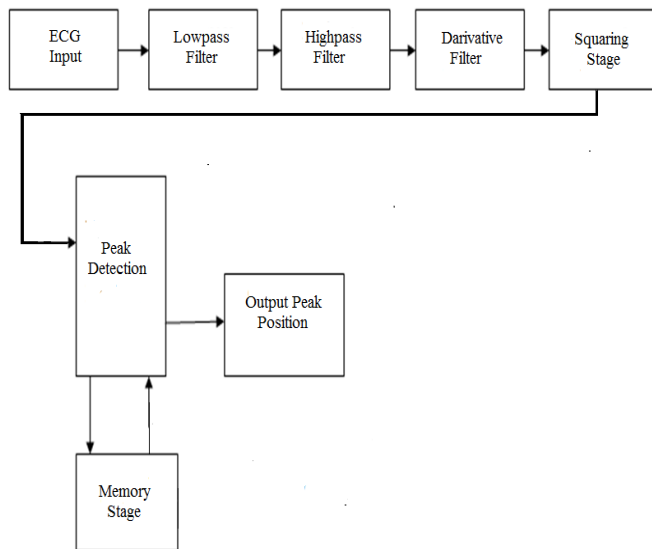


**Figure 3:** stages of QRS detection algorithm

This algorithm uses a hybrid of several processing methods, drawing heavily on digital filtering techniques and sophisticated peak selection rules. In this algorithm the QRS detector consists of three stages that are expanded on below:
1. Linear digital filtering
2. Nonlinear transformation
3. Decision rule algorithms

**I. Preprocessing Stage:**
The preprocessing consists of a number of filtering stages. These filters remove the unwanted noise signal picked up by the ECG due to interferences with the power lines within the room where recording is carried out. In this algorithm preprocessing consists of lowpass filter, highpass filter, Derivative Filter, Squaring stage and integration.

**Lowpass Filter**
The second order lowpass filter is used in this algorithm and the transfer function of the filter is given by equation

$$H(Z) = \frac{(1-Z^{-6})^2}{(1-Z^{-1})^2}$$

And its corresponding differential equation is
Y(nT)=2y(nT-T)+x(nT-6T)+$x$(nT-12T)Where T is sampling period and n is arbitrary constant. The cutoff frequency of the filter is about 11Hz.The gain of this lowpass filter is 32db. The filter introduces a delay of 6 samples in next stages. The lowpass filter removes all the high frequency spikes or noise from input ECG signal. As we are designing this algorithm using VHDL so all filters are implemented in modelsim

simulator. The direct form structure of lowpass filter is as shown in following figure. The lowpass filter is designed using number of registers and adders. The output of this lowpass filter is provided as an input to the highpass filter. This filter is used to remove noise.
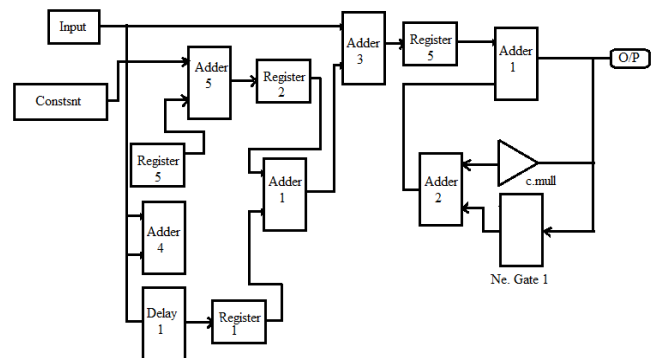


**Figure 4:** Lowpass Filter Implementation In System Generator

**Highpass Filter**
ECG signal do not retain at a constant DC level at all the times. Sometimes they are raised to higher or reduced to lower DC level. In this design the highpass filter comes after the lowpass filter removes the low frequency signal or DC offset signal and set it to zero level. The transfer function of the highpass filter is

$$H(Z) = \frac{\frac{1}{32} + Z^{-16} - Z^{-17} + \frac{1}{32}Z^{-32}}{1-Z^{-1}}$$

And its corresponding differential equation is
$$y(nT) = y(nT-T) + \frac{x(nT)}{32} + x(nt-17T) + \frac{x(nT-32T)}{32}$$

As it is a highpass filter, it removes low frequency signals hence its cutoff frequency is 5 Hz. The gain of this particular filter is 32 and when this filter is implemented it introduces a delay of 16 samples for the input to the next stage. The output of this stage is provided as a input to the next filtering stage i.e. derivative filter.
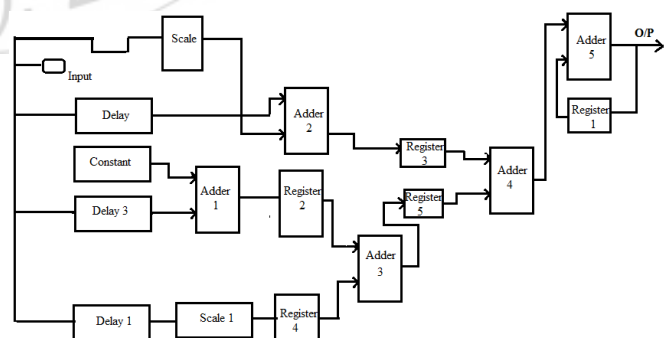


**Figure 5:** Highpass Filter Implementation In System Generator

**Derivative Filter**
Derivative filter is used to find the slope information in ECG filter. This technique of finding slope is very popular among all ECG analysis algorithms. The Differential equation and transfer function of this filter are given below.

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$$Y(nT) = \frac{2x\,(nT) + x\,(nT-1) - x\,(nT-3) - 2x\,(nT-4)}{8}$$

$$H\,(z) = \frac{2 + Z^{-1} - Z^{-3} - 2Z^{-4}}{8}$$

This filter introduces a delay of two samples. The output of preprocessing stage is provided to the peak detection stage.

**II. Peak Detection:** In this algorithm the peak detection is carried out by thresholding method. In this stage the first 400 samples are initially read and threshold is initialized to 30% of maximum value among all 400 samples. Then the input sample is compared with the threshold value, if the sample value is greater than the threshold value then the control moves to the next stage. Like this the point which lies in QRS region are detected. Once these points are detected then they are compared with each other and highest value among them is located.

## 2. Results

The results of presented system are obtained by using ECG signal from MIT BIH database as input. Following are the results of presented ECG QRS Detection Algorithm.
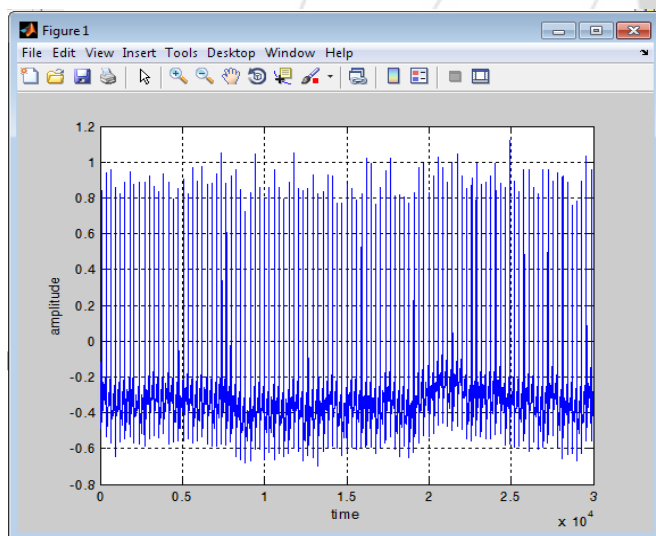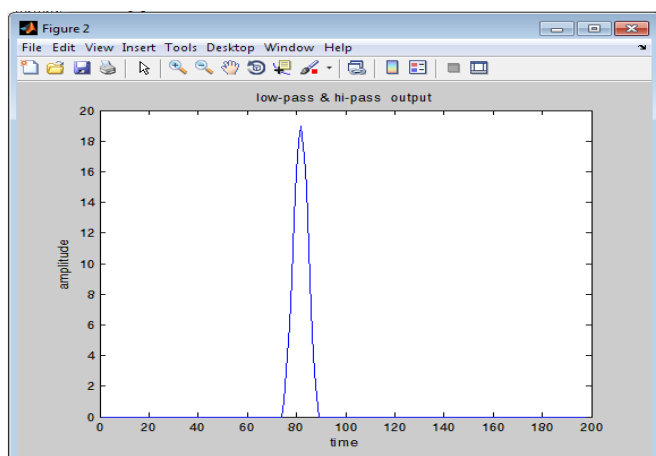


**Figure 1:** Input ECG Signal
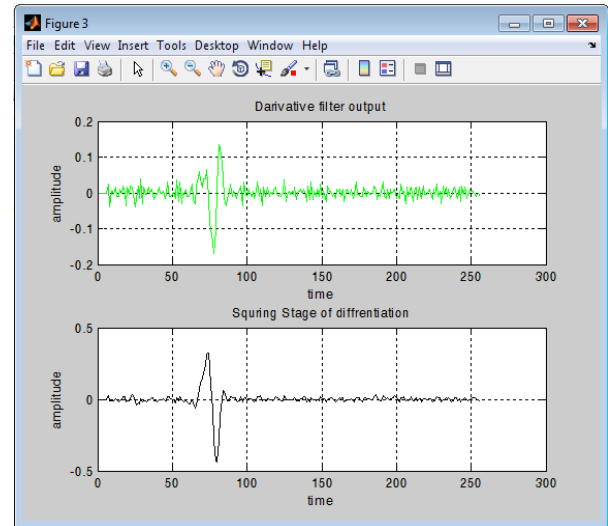


**Figure 2:** output of Bandpass Filter



**Figure 3:** Output of Derivative and Squaring Filter
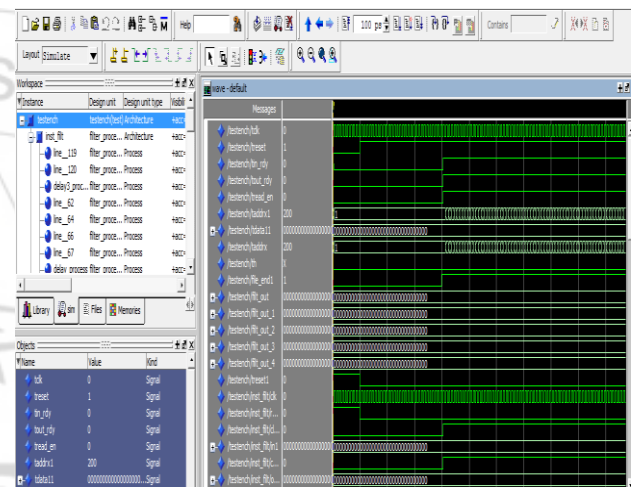

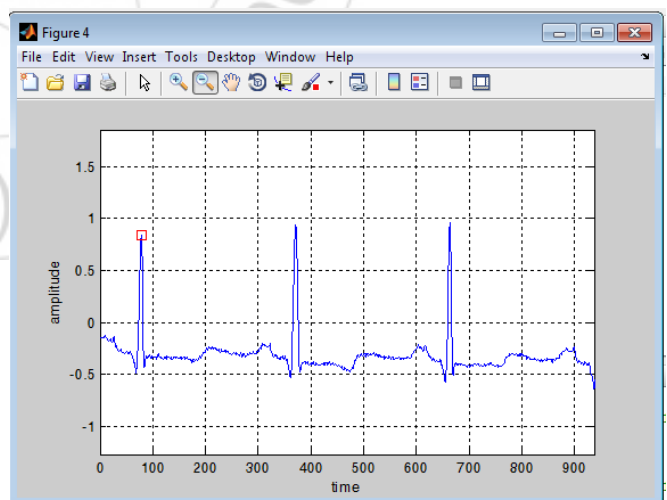
**Figure 4:** Output of QRS Detection Algorithm in Modelsim.



**Figure 5:** Output of QRS Detection Algorithm in Matlab



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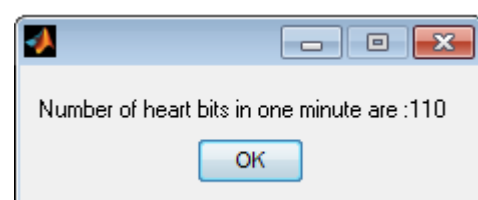
## 3. Conclusion

This paper has presented a novel algorithm for QRS detection based on filtering and thresholding and its implementation. The algorithm is evaluated with MIT/BIH standard ECG database to achieve a good detection rate and accuracy. The obtained results of the system are compared and validated by an expert cardiologist.

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