An Improved QRS Complex Detection for Online Medical Diagnosis

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Abstract—This paper presents the work of signal discrimination specifically for Electrocardiogram (ECG) waveform. ECG signal is comprised of P, QRS, and T waves in each normal heart beat to describe the pattern of heart rhythms corresponds to a specific individual. Further medical diagnosis could be done to determine any heart related disease using ECG information. The emphasis on QRS Complex classification is further discussed to illustrate the importance of it. Pan-Tompkins Algorithm, a widely known technique has been adapted to realize the QRS Complex classification process. There are eight steps involved namely sampling, normalization, low pass filter, high pass filter (build a band pass filter), derivation, squaring, averaging and lastly is the QRS detection. The simulation results obtained is represented in a Graphical User Interface (GUI) developed using MATLAB.

Keywords—ECG, Pan Tompkins Algorithm, QRS Complex, Simulation

I. INTRODUCTION

BIOLOGICAL signal carries physical information or signatures of any physiological events [1]. Any corresponding waveforms can further be analyzed in terms of its amplitude, time duration, intervals between events, energy distribution and frequency contents.

The accuracy of any Electrocardiogram (ECG) waveform extraction plays a vital role in helping a better diagnosis on any heart related illnesses. Normal ECG should consists of several parts include P wave, QRS complex and T wave. These waves reflect the heart's activity such as P wave produced by muscle contraction of Atria and its duration indicates the Atrial enlargement. Q wave gives the first negative value and typically supposed to be 25% less than the R wave value [2]. Next, the R wave marks the ending of Atrial contraction and the beginning of Ventricular contraction. The narrow and higher R wave shows a physically strong heart. QRS complex represents Ventricular contraction and the value usually is larger compared to P.

Physiologically, this is due to higher muscle density in Ventricle as opposed to Atria. T wave shows the ending of Ventricular contraction usually is slight round and symmetrical [1]-[3].

II. PAN TOMPKINS ALGORITHM

The works of Pan Tompkins greatly influence the QRS detection as compared to others. A survey of literatures signifies this approach as one of important algorithm in detecting QRS peak [4].

A. Overview

QRS detection is rather a difficult process. Several types of noise plays major problem such as muscle noise, artifacts noise due to electrode usage, power line interference and baseline wander can be reduced by applying digital filter [4]. Moreover, by using digital filter the signal to noise ratio (SNR) can eventually be improved.

This algorithm developed ways of detection based on slope, amplitude and width of QRS pattern. Due to various noises available that may distort the QRS signal, filtering is the best way to suppress any unwanted signal. The algorithm used the following architecture:

1) Linear filter- includes a band pass filter, a derivative and a moving window integrator.
2) Non-Linear Transformation - Signal amplitude squaring.
3) Decision Rule Algorithm - Adaptive Threshold and T-wave Discrimination as T wave provides the last segment of any ECG signal present.

III. METHODOLOGIES

By using ECG Simulator, KL-73001 Electrocardiogram ECG Module and KL-71001 Biomedical Measurement System, several experiments have been carried out to generate ECG samples signals shown by fig. 1.
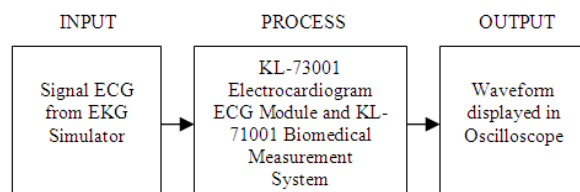
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Fig. 1 Block Diagram

Refer to fig.2, in extremity lead measurements; the right foot is always used as reference background. Through the combination of the right arm, left arm, and left foot, six ECG lead signals that include Lead I, Lead II, Lead III, aV_R, aV_L and aV_F can be measured. For consideration of hardware cost, a circuit with multiple-lead one-channel is designed in most cases.

In general, the frequency range is from 0.1 to 100 Hz and the maximum amplitude is 1 mV in a normal ECG signal. Furthermore, to avoid electrical shock caused by leakage from the power supply or measuring instrument, the isolation concept must be incorporated in designing a circuit for ECG detection. The bandwidth of the band-pass filter is from 0.1 to 100Hz, and the gain amplifier can magnify, with an amplification factor of 10.
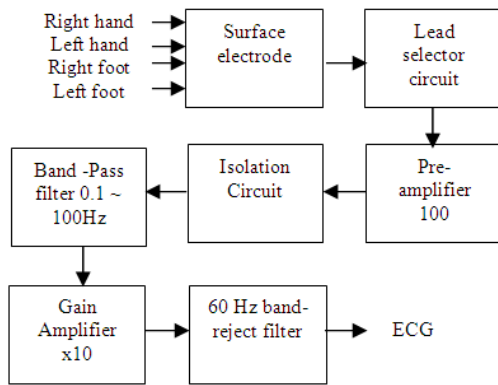

Fig. 2 Block Diagram of ECG Measurement Circuit

A. Filter Design

This section describes the important criteria for filter design process. A recursive low pass filter is designed with sampling rate f_s = 200 Hz and cut off frequency f_c = 11 Hz. The transfer function H(z) is given as in (1) and the differential equation y[n] as in (2).

$$H(z) = \frac{1}{32}\left[\frac{(1-z^{-6})^2}{(1-z^{-1})^2}\right] \quad (1)$$

$$y[n] = 2y[n-1] - y[n-2] + 0.03125[x[n] - 2x[n-6] + x[n-12]] \quad (2)$$

While a high pass filter is designed with and all pass filter minus a low pass filter such as the cut off frequency f_c = 5 Hz and producing delay of 80ms. The transfer function H(z) is given as in (3) and the differential equation y[n] as in (4). The finalize differential equation is given as in (5).

$$H(z) = \left[\frac{(1-z^{-32})}{(1-z^{-1})^2}\right] \quad (3)$$

$$y[n] = y[n-1] + x[n] - x[n-32] \quad (4)$$

$$p[n] = \left[x[n-16] - \frac{1}{32}y[n-1] + x[n] - x[n-32]\right] \quad (5)$$

After filtering, the QRS signal is differentiated to give the slope information. As for a derivative operator, it uses the differential equation as in (6).

$$y[n] = \left(\frac{1}{8}\right)\left[2x[n] + x[n-1] - x[n-3] - 2x[n-4]\right] \quad (6)$$

Next, the squaring function helps to makes all the distinctive points positive. This will further suppress the P and T waves while emphasizing on higher frequencies. The differential equation is given as (7).

$$y[nT] = [x[nT]]^2 \quad (7)$$

After that, the moving window function will further integrate the obtained signal to produce a waveform with smoothed features. For the chosen sampling rate, the suitable window was identified to be 30. The implementation is governed by the following equation as in (8).
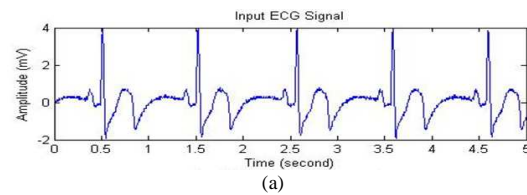
$$y[n] = \left(\frac{1}{N}\right)\left[x[n-(N-1)] + x[n-(N-2)] + ... + x[n]\right] \quad (8)$$

Adaptive threshold means a peak is said to be detected whenever the final output changes direction within a specified intervals.

IV. RESULTS AND ANALYSIS

The experiments were carried out to obtain various ECG signal samples to help further classification and QRS complex detection. Then, the digitized result is simulated using MATLAB to clearly show all the steps involved and events related to Pan-Tompkins algorithm.

A graphical user interface (GUI) was later developed to facilitate the MATLAB simulation. Other purpose of having the GUI is to help viewing process become easier. The detected QRS peaks were marked in different color.

(a)

Fig. 4 Developed GUI in MATLAB

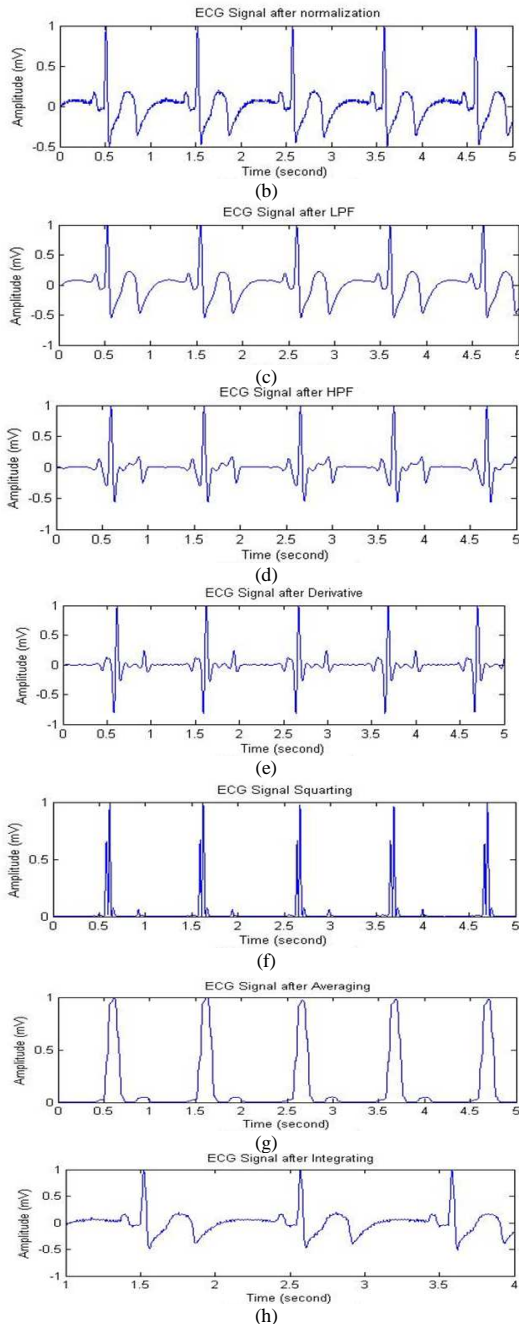Fig. 5 QRS complex detected is further marked

Fig. 3 QRS detection algorithm steps for a normal ECG from experiment done. (a) Original signal. (b) Output after normalization. (c) Output from low pass filter. (d) Output from high pass filter. (e) Output signal after derivative function. (f) Output signal after squaring. (g) Output after signal averaging. (h) Output after integration function

The simulated results obtained were further manipulated in MATLAB GUI shown in fig. 4 and fig. 5 below.
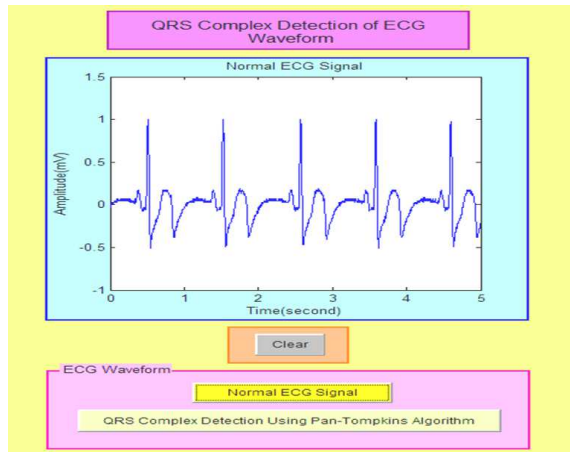
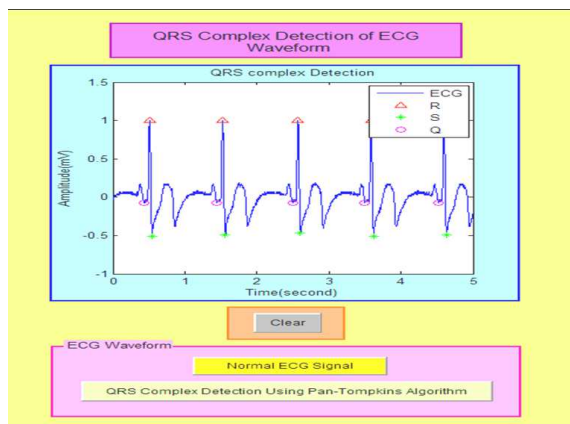In line with the above results, a validity test has been performed to ensure the reliability of this method. The test is widely known as Heart Rate Variability (HRV) test. Since this is done in time domain analysis, time domain measures were employed. The technique uses Hillbert Transform to help extracting several parameters which are important for QRS complex validation. The parameters are:

1) Q points.
2) T points.
3) QT intervals.
4) RR intervals.
5) RR mean.
6) RR standard deviation.

Other than that, the amplitude or magnitude of each peak (Q,R,S) were also quantified and checked to ensure the regularities of data does not exhibit any abnormalities such as to present any missing heart beats. The result is given in Table I below.

TABLE I
QRS COMPLEX DETECTION VALUES

Amplitude Sample	Q	R	S	QRS Avg.
Raw data 1	-0.0612	1	-0.4898	Q = -0.0612
	-0.0612	1	-0.4694	R = 0.9959
	-0.0612	0.9796	-0.4490	S = -0.4735
	-0.0612	1	-0.4898	
Raw data 2	-0.0566	0.9811	-0.3774	Q = -0.0566
	-0.0566	0.9811	-0.3774	R = 0.9849
	-0.0566	0.9811	-0.3774	S = -0.3774
	-0.0566	0.9811	-0.3774	
Raw data 3	-0.0566	0.9811	-0.3774	Q = -0.0566
	-0.0566	0.9811	-0.3774	R = 0.9849
	-0.0566	1	-0.3774	S = -0.3774
	-0.0566	0.9811	-0.3774	
Raw data 4	-0.0612	1	-0.4694	Q = -0.0612
	-0.0612	1	-0.4490	R = 0.9959
	-0.0612	1	-0.4898	S = -0.4694
	-0.0612	0.9796	-0.4694	
Raw data 5	-0.0577	1	-0.3846	Q = -0.0577
	-0.0577	1	-0.3846	R = 1
	-0.0577	1	-0.3846	S = -0.3846
	-0.0577	1	-0.3846	

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