DETECTION OF HEART BLOCKS IN ECG SIGNALS BY SPECTRAL ESTIMATION TECHNIQUES

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Detection of Heart Blocks in ECG Signals by Spectral Estimation Techniques

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ABSTRACT

The electrocardiogram (ECG) is a non-invasive test that records the electrical activity of the heart and is important in the investigation of cardiac abnormalities. Each portion of the ECG waveform carries various types of information for the cardiologists analyzing patient's heart condition. ECG interpretation at the present time remains dependent manually in time domain. It is difficult for the cardiologists to make a correct diagnosis of cardiac disorder. A computerized interpretation of ECG is needed in order to make the diagnosis more efficient. This paper discusses the use of digital signal processing approaches for the detection of heart blocks in ECG signals. Spectral estimations such as the periodogram power spectrum, Blackman-Tukey power spectrum and spectrogram time-frequency distribution are employed to analyze ECG variations. Window functions are applied to the spectrums which are Boxcar, Hamming and Bartlett window. Seven subjects are identified: normal, first degree heart block, second degree heart block type I, second degree heart block type II, Third degree heart block, right bundle branch block and left bundle branch block. Analysis results revealed that normal ECG subject is able to maintain higher peak frequency range (8 Hz), while heart block subjects revealed a significant low peak frequency range (< 4 Hz) for both the periodogram and Blackman-Tukey method. The results revealed that the periodogram power spectrum with Boxcar window can be used to differentiate between normal and heart block subjects, while the spectogram time-frequency distribution is used to give better characterization of ECG parameters in term three dimension: time, frequency and power intensity. These analyses can be used to construct ECG monitoring and analyzing system for heart blocks detection.

KEYWORDS

ECG, power spectral estimations, time-frequency distribution and heart blocks

1. INTRODUCTION

An electrocardiogram (ECG) is a recording of the heart's electrical activity which allows cardiologists to evaluate the heart's rate, rhythm and certain cardiac problems. A highly sensitive electrocardiograph tools can help cardiologists to detect various heart irregularities, cardiac diseases and damages [1]. The ECG interpretation is important for cardiologists to decide diagnostic categories of cardiac problems. Conventional technique of visual analysis is more complicated and requires experience and time [2]. Thus, there is a need to develop a computerized technique that can assist cardiologists to detect some common heart diseases.

For ECG based interpretation of cardiac abnormalities, different methods have been adopted based on time domain or frequency domain features [3]-[5]. Autocorrelation function and cross correlation function is

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1. INTRODUCTION

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For ECG based interpretation of cardiac abnormalities, different methods have been adopted based on time domain or frequency domain features [3]-[5]. Autocorrelation function and cross correlation function is performed in [6] to determine most accurate techniques to represent ECG, while the use of neural networks for the classification of diseases has been well established [2],[7].

This research looks the possibility of using digital signal processing approaches in the interpretation of the ECG signals. Power spectral estimation techniques such as periodogram and Blackman Tukey power spectrum estimations have been analyzed and the spectrogram time-frequency distribution is performed to differentiate between normal ECG signal and heart block subjects. Several window functions are employed to the spectral and time-frequency estimate which are Boxcar, Hamming and Bartlett window function. The purpose is to analyze the best techniques that can represent spectrum parameter of the ECG signals.

Using these algorithms, the subjects that are classified are:

- Normal
- First degree heart block
- Second degree heart block type I
- Second degree heart block type II
- Third degree heart block
- Right bundle branch block
- Left bundle branch block

2. THEORY

2.1 Electricity of the Heart

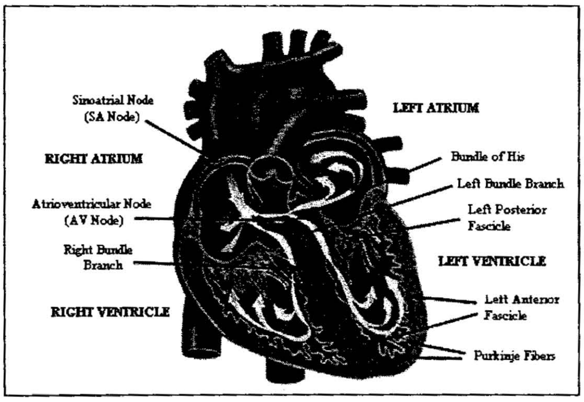


Fig. 1. Cardiac conduction system

The contraction of any muscle is associated with electrical changes called 'depolarization', and electrodes attached to the surface of the body can detect these changes. The heart has four chambers, from the electrical point of view it can be thought of as having only two because the two atria contract together and then the two ventricles contract together. Fig. 1 shows the parts of cardiac conduction system.

The electrical activity of the heart originates in the sinoatrial node (SA node), situated in the wall of the right atrium. The impulse then rapidly spreads through the right atrium to the atrioventricular node (AV node). After a delay at AV node, the impulse travels slowly through the bundle of his, the bundle branches, the Purkinje network, and finally the ventricular muscle. The first area of the ventricular muscle to be activated is the interventricular septum, which activates from left to right. Finally, the impulse divides into the Purkinje network of fibers that proceed vertically to the surface of the heart [8].

2.2 Electrocardiogram (ECG) Signals

The ECG waveform is divided into P, Q, R, S, T and U elements [1]. The P wave corresponds to atrial depolarization that shows contraction of both left and right atria. Normal duration of P wave is between 0.06 to 0.12 seconds. The QRS complex represents depolarization of the ventricles. The duration of the QRS complex shows how long excitation takes to spread through the ventricles and must less than 0.1 seconds for normal ventricles contraction. The T wave represents ventricles repolarization which setting up the cardiac muscle for another contraction. Sometimes it will follow by U wave that represents the purkinje fibers repolarization.

The PR interval is the conduction time required for an electrical impulse to be conducted from the atria to the ventricles. The duration is normally 0.12 to 0.20 seconds and is important to indicate heart block problems. The QT interval is measured from the beginning of the QRS complex to the end of the T wave. A normal QT interval is about 0.40 seconds. The ST segment connects the QRS complex and the T wave. It represents the measured time between ventricular depolarization and the beginning of ventricular repolarization which normally last about 0.08 seconds.

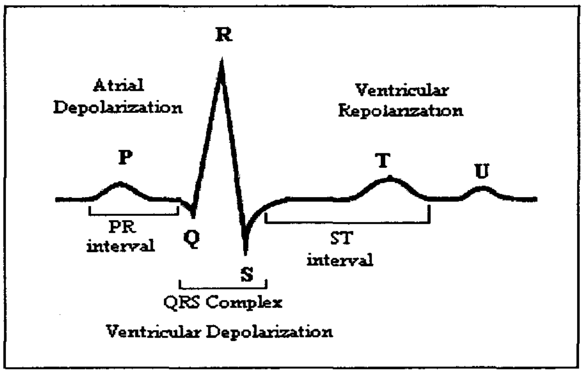


Fig. 2. Points and elements of ECG signal

The normal period of one cardiac cycle is between 0.6 seconds to 1.0 seconds, which it represents the heart rate or the number of heart beats per minutes (BPM). Thus, the heart rate for normal rhythm is between 60 to 100 BPM. The ECG strips is best interpreted from lead II or lead V_1 which the lead shows the most clearly rhythm of the heart according to Einthoven's Triangle [9]. Fig. 2 shows normal ECG signal from the standard lead II.

2.3 Heart Block Problems

Heart block problems occur as a result of incorrect impulse conduction through the cardiac muscles. The depolarization wave normally spreads from the SA node to AV node, bundle of his and the bundle branches. The conduction disturbances of this wave can be delayed or block at any point. Heart block problems can be divided into two common classes. They are [1]

2.3.1 Conduction Disturbances in the AV Node and Bundle of His

A block or abnormal conduction between the atria (SA node) and ventricles (AV node or bundle of his). The ECG pattern is characterized by prolongation of the PR interval longer than 0.2 seconds. The type of conduction disturbances in the AV node and bundle of his are

- First degree heart block (known as first degree AV block)
- Second degree heart blocks type I and type II (known as Mobitz type I and type II or second degree AV block type I and type II)
- Third degree heart block (known as complete heart block)

2.3.2 Conduction Disturbances in the Right and Left Bundle Branches

A block or abnormal conduction through iether the right or left bundle branches and there will be a delay in the part of ventricular muscle. The ECG pattern is characterized by widening of the QRS complex greater than 0.12 seconds. Right bundle branch block indicates problems in the right side of the heart while left bundle branch block is usually indicates heart diseases in the left side.

2.4 Periodogram Power Spectrum Estimation

The periodogram power spectrum estimate [10], [12] represents the distribution of the signal power over frequency. From the spectrum, the frequency content of the signal can be estimated directly from the frequency sample values that correspond to the peak value. It is calculated based on the windowed Fast Fourier Transform (FFT) algorithm which represent the frequency contain of the discrete-time waveform. The periodogram is calculated for the ECG waveforms as follows:

$$S_w(k) = \frac{1}{N}\left|\sum_{n=0}^{N-1} v(n)e^{-j\frac{2\pi kn}{N}}\right|^2 \qquad (1)$$

$$0 \le k \le N-1$$

Where $S_w(k)$ is the frequency representations of the discrete-time ECG waveform, $v(n)$.

2.5 Blackman-Tukey Power Spectrum Estimation

The Blackman-Tukey power spectrum constructs an estimate of the power spectrum using a windowed FFT, or a periodogram of the autocorrelation function of the discrete-time waveform[10],[12]. The resulting power-spectrum estimate is also called a correlogram. In the Blackman-Tukey approach, the power spectrum $P(\omega)$ is estimated by:

$$P_{xx}(\omega) = \frac{1}{M}\left|\sum_{n=0}^{M-1} R_{xx}(n)w(n)e^{j\omega n}\right|^2 \qquad (2)$$

Where $R_{xx}(n)$ is the autocorrelation function, N is the window length, and $w(n)$ is the window function. Several window functions such as Boxcar, Bartlett and Hamming can be used in the Blackman-Tukey method.

2.6 Spectogram

Limitation of the power spectrum estimate is it represents only the frequency content of the signal and does not gave any information of its temporal characteristics. This is resolve by representing the signal jointly as a time-frequency representation [11], [13]. For an arbitrary discrete-time waveform of length *N*, the spectrogram time-frequency representation is calculated as follows:

$$\rho_x(n,k) = \frac{1}{M}\left|\sum_{n=0}^{M-1} w(n-m)x(n)e^{-j\frac{2\pi kn}{M}}\right|^2 \qquad (3)$$

$$0 \le k \le N-1$$

Where $x(n)$ is the discrete-time waveform, $w(n)$ is the window function of length *M*, and *M* is chosen to be less than *N*. Any one of the popular window functions such as Hamming, Hanning or Blackman can be used in the spectogram.

2.7 Window Function

From implementation perspective, it is desired to limit the length of the discrete signal. A window function is multiplied to the signal to smooth the spectrum and reduce the sampling errors on the estimations[10]. Several window functions can be used in the estimations are:

- Boxcar (Rectangular)

$$w(n) = 1 \qquad 0 \le n \le M-1$$
$$= 0 \qquad \text{elsewhere} \qquad (4)$$

- Bartlett (Triangular)

$$w(n) = 1 - \left|1 - \frac{2n}{M-1}\right| \qquad 0 \le n \le M-1$$
$$= 0 \qquad \text{elsewhere} \qquad (5)$$

- Hamming

$$w(n) = 0.54 - 0.46\cos\left(\frac{2\pi n}{M-1}\right) \qquad 0 \le n \le M-1$$
$$=0 \qquad \text{elsewhere} \qquad (6)$$

Where $w(n)$ is the chosen window function of length M.

3. DATA ACQUISITION AND IMPLEMENTATION

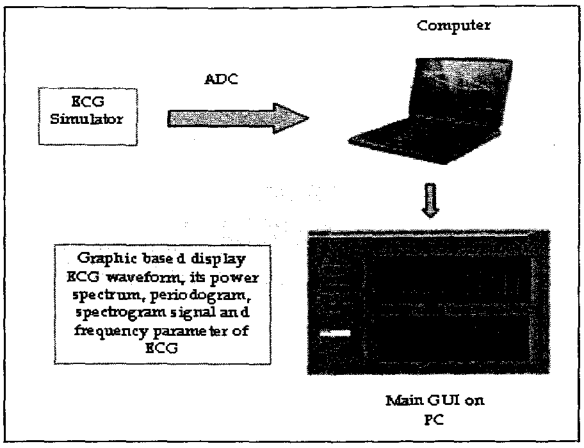


Fig. 3. Block diagram of project

All ECG data were obtained from ECG simulator and is transferred into a computer for analysis and implementation purposes. The periodogram, Blackman-Tukey and spectrogram of the signals are computed in Matlab for pre-processing analysis. Besides that, the relevant software is developed and coded in Visual Basic 6.0 for signal monitoring and further implementation of the project. Fig. 3 shows the block diagram of project implementation in computer.

3.1 Offline Data Acquisition

The ECG data were acquired from ECG simulator model MedSim 300B from DNI NEVADA INC. The machine performs as patient simulator that generates the 12-lead ECG waveform. Each signal lead referenced to RL (right leg) electrode, and provides selectable parameters including rate, amplitude, ST segment deviation, axis deviation and arrhythmias. The ECG signals are transferred into a computer by PC-ECG card for display and storage purposes and is saved in the file *.csv* format.

Table 1 is an example of ECG data, which consists of 4500 data that taken in nine seconds. To analyze, the data from 'leadtype:Limb+Augmented' column, which is taken from lead II. The data is sampled at sampling frequency 500 Hz and transferred into the file *.txt* format for further analysis and implementation.

Table 1. ECG data stored in computer

version: 2.1i	location: medication: None	operator: Dr Karim Wan	display: 0	leadtype: Limb+Augmented	rhythmstrip: III	mainsfreq: 60	swnotchfilter: 0
2106	2142	2029	1918	1906	1936	1952	1916
2106	2142	2021	1918	1906	1936	1952	1916
2106	2142	2017	1910	1902	1936	1952	1916
2106	2138	2013	1910	1902	1936	1948	1912

3.2 Analysis in Matlab

The periodogram, Blackman-Tukey and spectrogram of the ECG signals are computed in Matlab for pre-processing analysis. Boxcar, Hamming and Bartlett window functions are applied to the algorithms.

pectrogram time-frequency analysis is performed in order to give better characterization of ECG parameters in erm of time, frequency and power intensity dimensions. Based on the analysis, the best power spectrum analysis s chosen and combined with the spectogram representation for actual implementation.

.3 Algorithms Implementation

The algorithm is developed and coded in Visual Basic 6.0 for actual implementation. Fig. 4 shows the main raphical user interface (GUI) display that controls and represents the result on the computer. The first column hows the control buttons for normal and heart blocks signals, while the peak value for spectrum analysis is hown on the next row of the first column. It represents the signal frequency of ECG waveform.

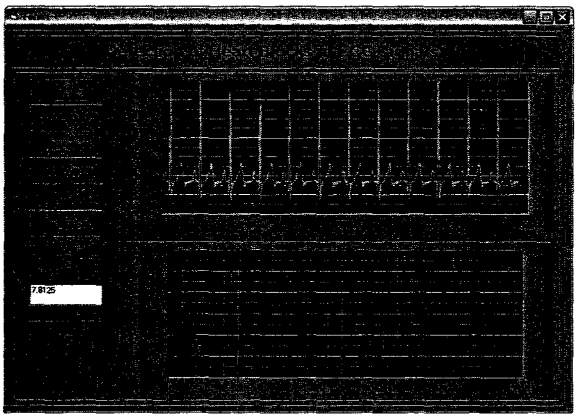


Fig. 4. Main GUI display on computer

The time domain ECG waveform for a chosen signal is represented on the next column of the GUI. Simultaneously, the spectrum frequency waveform is represented below the time domain waveform. This is shown in the graph in Fig. 5. The vertical scale represents power while the horizontal represents frequency.

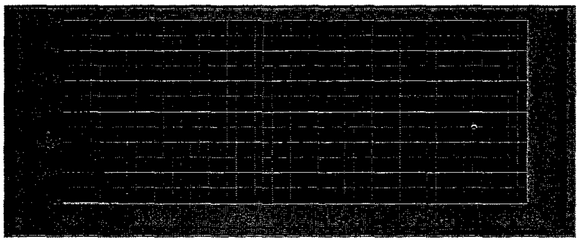


Fig. 5. Spectrum frequency for ECG waveform

The spectogram analysis can be chosen from GUI menu. This is a contour plot when the vertical scale represents frequency, horizontal scale represents time and the power is represented in terms of the color intensity of the plot. The highest power is represented as blue color while the lowest power by yellow color. Fig. 6 shows an example of a contour plot of ECG waveform.

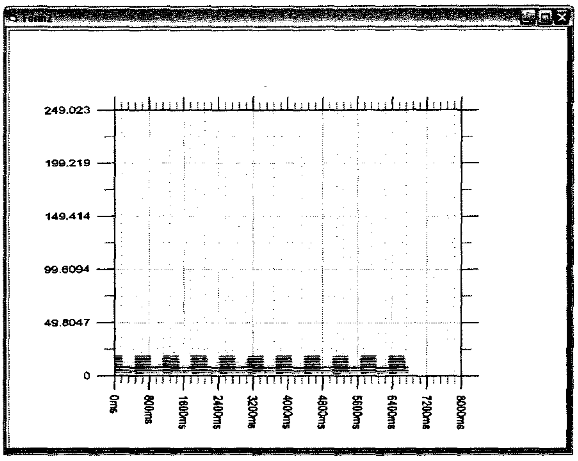


Fig. 6. Spectogram for ECG waveform

4. RESULTS

Analysis was made by pre-processing simulations using Matlab and actual implementation on the Visual Basic 6.0. The objective is to show how each of the method can differentiate between the ECG waveforms and identify the heart block subjects.

Analysis was made by using different methods in power spectral and the spectogram algorithm. The periodogram power spectrum using Boxcar and Hamming window, Blackman-Tukey power spectrum using Boxcar and Bartlett window and the spectogram by using Boxcar window function have been simulated in Matlab. The window length used is 512 sample size and sampling frequency 500 Hz is applied for each of the algorithms.

4.1 Analysis in Matlab

Fig. 7 and 8 show simulation results for normal ECG and third degree heart block subject by using periodogram power spectrum with Boxcar window, Blackman-Tukey power spectrum with Bartlett window and the spectogram time-frequency analysis using Boxcar window.

For normal subject, the periodogram power spectrum shows that the signal frequency is 7.8 Hz, while Blackman-Tukey spectrum shows similar peak value with smother spectrum. The spectogram result shows that the signal frequency lies at all times during the observation interval.

For third degree heart block subject, the periodogram power spectrum shows that the signal frequency is 3.9 Hz and Blackman-Tukey method gives approximate similar result. The spectogram represents that the signal frequency is only appears within the duration of 500 ms periodically for every 2000 ms. It is not shown on the power spectrum representations.

The result show that the various windows of the same widths give similar frequency estimates for both normal and heart block subjects in the power spectrum estimations, while the spectogram analysis gives more characterization in time and frequency intervals of the waveforms. The comparison between each power spectrum estimations is shown in Table 2.

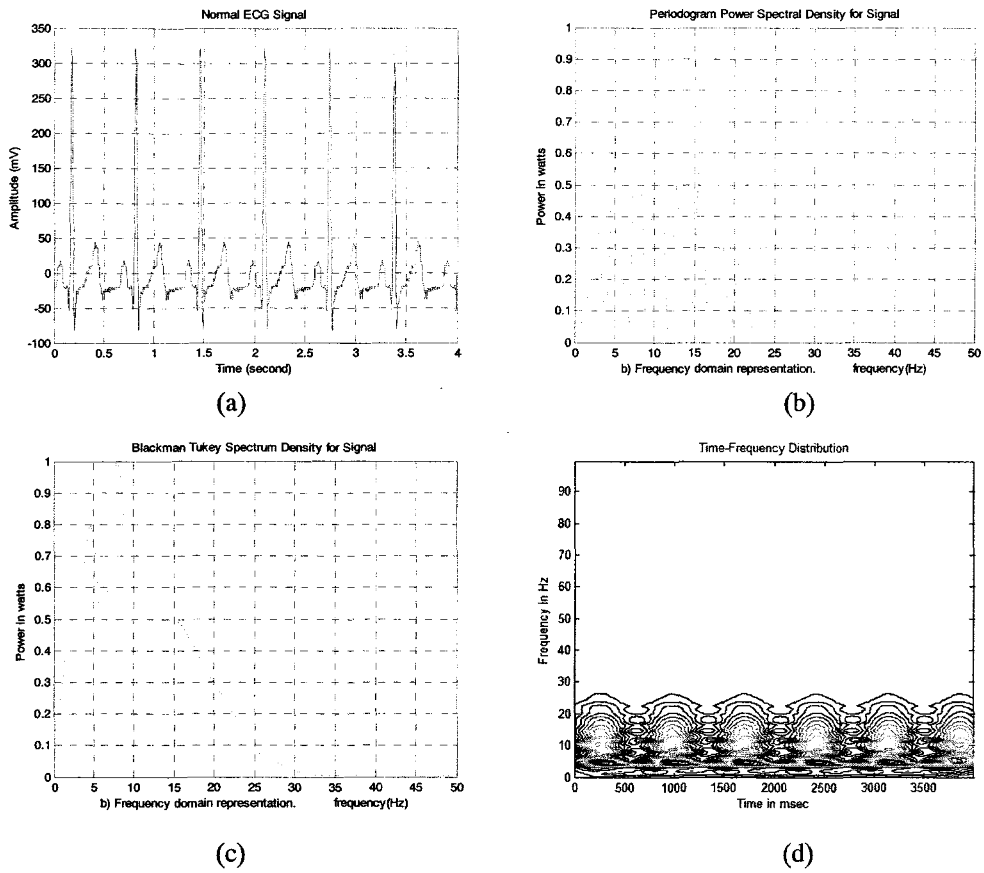
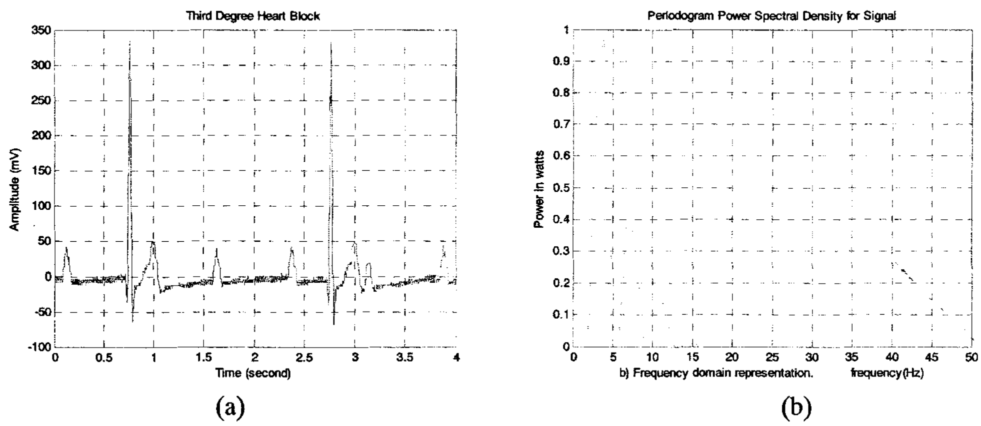
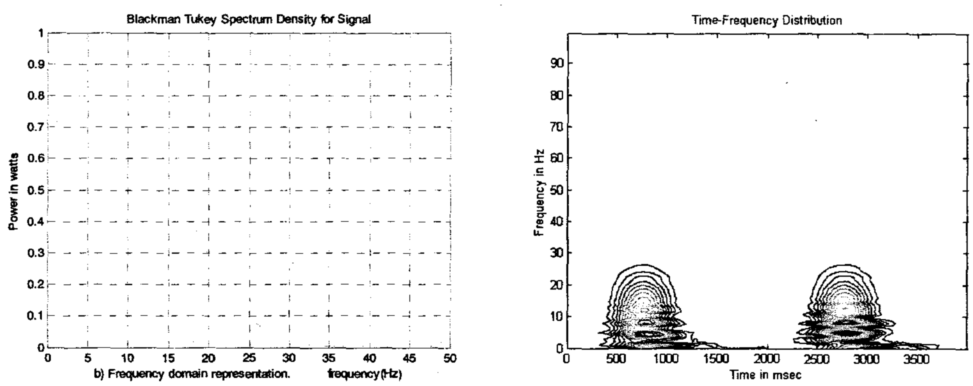


Fig. 7. Normal ECG waveforms: (a) Representation in time domain, (b) Representation in periodogram spectrum using Boxcar window, (c) Representation in Blackman-Tukey spectrum using Bartlett window, (d) Spectogram time-frequency distribution





(c) (d)

Fig. 8. Third degree heart block ECG waveforms: (a) Representation in time domain, (b) Representation in periodogram spectrum using Boxcar window, (c) Representation in Blackman-Tukey spectrum using Bartlett window, (d) Spectogram time-frequency distribution

Table 2. Comparison between periodogram and Blackman-Tukey power spectrum in ECG signals

ECG Subject	Periodogram power spectrum (Hz)		Blackman-Tukey power spectrum (Hz)	
	(Boxcar)	(Hamming)	(Boxcar)	(Bartlett)
Normal ECG	7.8	7.8	7.7	7.9
First degree heart block	3.9	3.9	4.0	4.0
Second degree heart block type I	4.0	4.0	4.0	4.0
Second degree heart block type II	3.9	3.9	3.9	3.8
Third degree heart block	3.9	3.9	4.5	4.5
Right bundle branch block	2.9	1.0	1.5	2.1
Left bundle branch block	2.9	3.9	3.9	3.5

4.2 Analysis in Actual Implementation

Analysis on actual simulation for each type of ECG waveform is done by using Visual Basic 6.0. Based on the analysis in Matlab, the periodogram power spectrum using Boxcar window function has been chosen for implementation, since the algorithm can characterized the frequency spectrum and peak value between normal and heart block subjects and it is easier to implement compared to the other power spectrum estimates. The periodogram power spectrum is combined with the spectogram time-frequency distribution to represent the ECG waveforms.

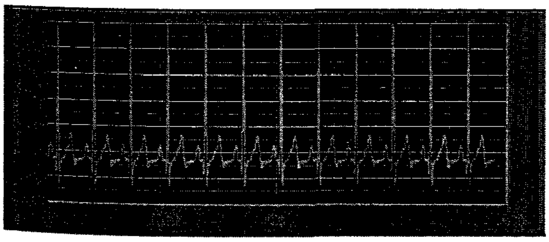
The obtained results of the signal frequency are presented in Table 3. The result shows that normal ECG subject is able to maintain higher peak frequency range (8 Hz), while heart block subjects revealed a significant low peak frequency range (below 4 Hz).

Table 3. Spectrum frequency of ECG signals

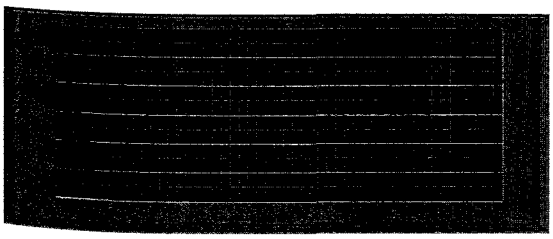
ECG Subject	Spectrum Frequency
Normal ECG	7.8 Hz
First degree heart block	3.9 Hz
Second degree heart block type I	4.0 Hz
Second degree heart block type II	3.9 Hz
Third degree heart block	3.9 Hz
Right bundle branch block	2.9 Hz
Left bundle branch block	2.9 Hz

Fig. 9 and 10 shows the waveform for normal and second degree heart block type II subjects. For the normal subject, the signal frequency is presented by the peak value of the power spectrum and time-frequency representation, while for the second degree heart block subject, the time-frequency representation provides additional information that shows the signal frequency is absence for the duration of 1600 ms during the observation on time interval and not on the power spectrum.

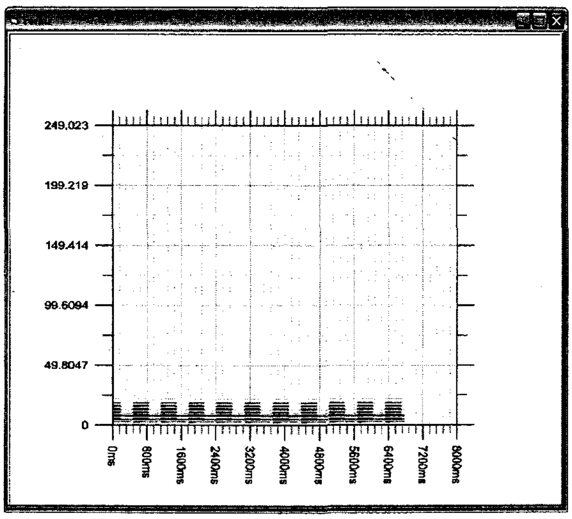
The analysis results revealed that the periodogram power spectrum can be used to differentiate between normal and heart block subjects, while the spectogram time-frequency analysis is used to provide additional information and give better characterization of ECG parameters for heart block subjects.



(a)

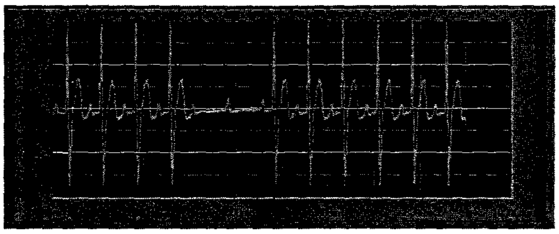


(b)

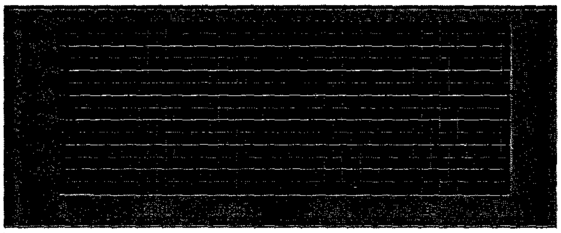


(c)

Fig. 9: Normal ECG signals: (a) Time domain representation, (b) Power spectrum representation, (c) Time-frequency representation



(a)



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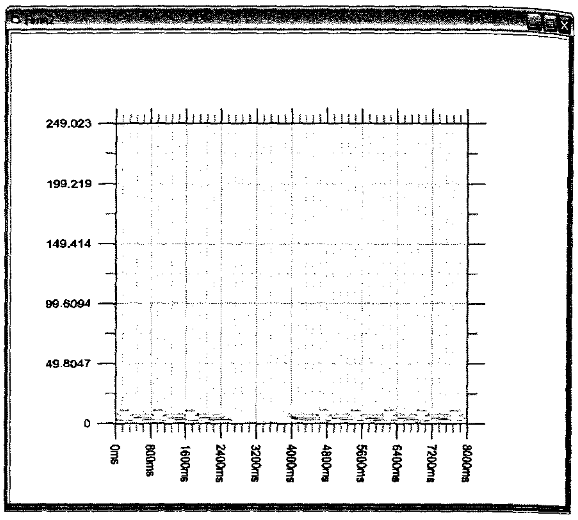

(c)

Fig. 10: Second degree heart block type II ECG signals: (a) Time domain representation, (b) Power spectrum representation, (c) Time-frequency representation

5. CONCLUSIONS

Analysis of simulated normal and heart block ECG subjects are presented by using signal analysis techniques such as periodogram power spectrum, Blackman-Tukey power spectrum and spectrogram time-frequency analysis. Besides the simulation in Matlab, the results are also available through a graphical user interface in Visual Basic 6.0.

Analysis on the power spectral estimation shows that periodogram and Blackman-Tukey method give approximate similar frequency value of ECG waveforms. Both algorithms can be used to differentiate between normal and heart block subject by using either Boxcar, Hamming or Bartlett window. The analysis shows that the various windows of the same window lengths give similar results. Periodogram power spectrum estimation using Boxcar window function is easier to implement and is used for implementation.

Analysis results shows that the spectrogram gives better characterization of heart blocks detection compared to power spectral estimations. The method provides additional information on power and frequency signal during the observation on time interval. The spectrogram analysis can therefore provide details of the frequency spread of heart blocks subjects whereas periodogram gives the frequency contain of the signals.

It can also be concluded that the combination of periodogram power spectrum and spectrogram time-frequency analysis provide a powerful means of studying ECG signals for heart blocks detection. These methods can be used to construct a real time ECG monitoring and analyzing system which helps cardiologists to identify heart block problems and take necessary actions to the patients.

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