ECG Feature Extraction and Cardiac Arrhythmia Detection Based on Time Domain Analysis for Automated Clinical Decision Support Systems

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ABSTRACT
Heart diseases continue to be a primary killer disease in both developed and developing countries. Cardiac problems are considered to be the most fatal in medical world. Abnormalities in the heart lead to different cardiac arrhythmias. Computer-assisted automatic detection of cardiac arrhythmias is important when dealing with heart problems. One of the main techniques for diagnosing heart disease is based on the electrocardiogram (ECG).This paper presents a real time algorithm based on time domain analysis using GNU octave simulation tool for the detection of different arrhythmia by extracting various features and vital intervals from ECG signals. The proposed method was tested over the MIT-BIH arrhythmia database.

KEYWORDS: Cardiac arrhythmia ,Electrocardiogram(ECG), GNU octave.

1. INTRODUCTION
Cardiovascular diseases are the leading cause of death globally and it is estimated to remain in the number one position. According to World Health Organization (WHO) estimate, cardiovascular diseases kill almost seventeen million people around the globe each year, with around twenty million people at a risk of sudden heart failure. Some of these lives can often be saved if acute care and cardiac surgery are provided within the so-called golden hour [14]. One of the main techniques for diagnosing cardiovascular disease is based on the Electrocardiogram (ECG).

The Electrocardiogram is a highly valuable diagnostic aid and clinical tool in modern medicine. This is primarily because a visual inspection of the recorded ECG wave form is critical to the correct diagnosis and treatment of cardiovascular diseases. Electrocardiogram (ECG) provides useful information of the condition of heart. The ECG interpretation is very important for cardiologists to choosediagnostic categories of heart related problems. Automatic analysis and classification of ECG can ease the burden of cardiologists and speed up the application [8].Conventional techniques of visual analysis is more complicated and requires experience and time. Thus, there is a need to develop computerized techniques that can assist cardiologists to detect some common heart diseases.

Heart monitoring solutions such as the Holter device requires highly accurate QRS detector. Arrhythmia monitors for mobile patients analyze the ECG graphical record in real time. When uneventful heartcondition appears, such a monitor can be programmed to immediately store an interval of the abnormal ECG for subsequent transmission to a central station where a physician can interpret it. Such a device requires a very accurate QRS recognition capability [5]. Thus, an accurate QRS detector is an important part of many ECG instruments.

A. ECG Signal
The electrical activity in the heart can be measured, non-invasively, with the use of the electrocardiogram which records this electrical activity over time. Electrocardiogram is the recording of electrical potential produced by the excitation of cardiac muscles. The word 'Electro' refers to electricity, 'cardio' refers to the heart, and 'gram' refers to recording of heart's electrical activity. The ECG signal is typically in the range of ±2mv .The clinical bandwidth used for recording a 12 lead ECG is 0.05-100 Hz. However for the intensive care patients and for ambulatory patients the bandwidth requirement is 0.5-50 Hz , A typical ECG tracing of a normal heartbeat as shown in figure I.

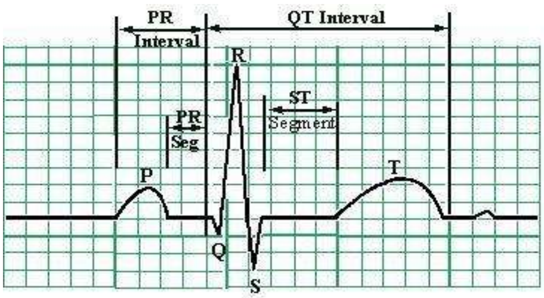


Figure I. ECG signal over one cardiac cycle

The propagation of the SA action potential through the atria results in contraction of the atria (depolarization), producing the P wave. The magnitude of the P wave is generally low (50-100μV) and time duration is about 100 ms. The PR interval begins with the onset of the P wave (P_i) and ends at the onset of the Q wave (Q_i). It represents the time of the conduction through the atria to the ventricles. Normal measurement for PR interval is 120ms-200ms. The QRS complex related to the period of ventricular contraction or depolarization. If either section of the heart is not functioning properly, the size of the QRS complex may increase. Normal measurement for QRS is 60ms-100ms. The ST segment begins at the end of the QRS complex (called J point) and ends at the beginning of the T wave. Normally, the ST wave measures less than 0.12 second . The T wave results from the repolarization of the ventricles and is of extended duration than the QRS complex. The duration of the T wave normally measures 0.20 second or less. The QT interval begins at the onset of the Q wave (Q_i) and ends at the end point of the T wave (T_t), representing the duration of the ventricular depolarization/ repolarisation cycle. The normal QT interval measures about 0.38 second.

B. Cardiac Arrhythmia

The SA Node generates the electrical impulse and begins the cascade of events that result in a heart-beat. For a standard healthy person the graphical record comes off as an almost periodic signal with change followed by re-polarization at equal intervals. Normal sinus rhythm is characterised by a daily rhythm.. Heart rate of normal sinus rhythm is about 60-100 bpm. However, sometimes this rhythm becomes irregular [18].Cardiac arrhythmia (also dysrhythmia) is a term for any of a large and heterogeneous group of conditions in which there is abnormal electrical activity in the heart.The heartbeat can be too quick or too slow, and will be regular or irregular.. Arrhythmia comes in varieties .It may be represented as a flutter in chest or generally "racing heart". The diagnosis of Arrhythmia requires Electrocardiogram. By studying ECG, Doctors can diagnose the disease and prescribe the required medications [18].Different arrhythmia conditions include Bradycardia, Tachycardia, Atrial Fibrillation etc.

Sinus Bradycardia:

The heart rhythm is regular,originates in the sinus node and looks normal but less than 60 beats per minute. The RR interval is longer and often more than one second. P waves are present and regular and each P-wave is followed by a QRS complex [18].

Sinus Tachycardia

The heart rhythm is regular, originates in the sinus node looks normal but at a rate greater than 100 beats per minute. The RR interval is shorter(usually less than 0.6 seconds). P waves are present and regular and each P-wave is followed by a QRS complex [18].

C. ECG Database

Several standard Electrocardiogramdatabases are available for complex QRS detection algorithms. Tests on well-annotated and validated databases provide reproducible and comparable results and hence for this work the most popular ECG data base MIT-BIH arrhythmia database is used. It contains 48 half-hour recordings of annotated ECG. Signals are sampled with a sampling rate of 360 Hz and 11-bit resolution over a 10 -mV range [20] . The presentwork makes use of 32 full length recordings for ecg feature extractions and for classification into normal and abnormal arrhythmia signal.

2. METHODOLOGY

This paper present a suitable algorithm for identifying different abnormalities related to heart such as bradycardia and tachycardia. It includes preprocessing, feature extraction, and different arrhythmia identification from the raw ECG signal.

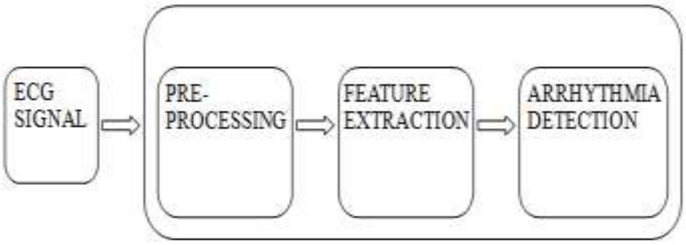


Figure II. Block diagram of the proposed method

Preprocessing stage removes or suppresses the noise from the ECG signal. The main noise that may affect ECG signal includes patient-electrode motion artifacts, EMG noise (Electromyographic noise) caused by muscle movement, baseline wandering etc. Preprocessing can be done by using a digital filter approach. For the diagnosis of heart problems it is necessary to extract various features from the preprocessed data. The feature extraction stage actually extracts useful information from the ECG signal such as QRS complex, RR interval etc. The detection of the R-peaks and consequently of the QRS complexes in an ECG signal provides information about heart rate, the conduction velocity, the condition of tissues with in the heart as well as various abnormalities.Based on the RR interval the heart rate can be computed and depending on this heart rate, the arrhythmia can be determined. The R waves of each cardiac cycle are detected and measuring the time between two consecutive R wave, heart rate can be determined. The normal heart rate should be in the range between 60-100 bpm(beats per minute). Any deviation from the normal value indicates an abnormal condition. That is, if the heart rate rises above 100 bpm, then an arrhythmia condition called tachycardia occurs and if the heart rate falls below 60 bpm then a condition called bradycardia occurs.

A. PAN-TOMPKINS Algorithm

QRS complex is the most distinguishable component in the ECG signal and its detection is of vital importance in response to the subsequent processing of ECG signal. The QRS detection algorithm introduced by Pan and Tompkins is the one of the popular and widely used algorithm for the extraction of the QRS complexes. Pan and Tompkins proposed a real time QRS detection algorithm based on analysis of the slope, amplitude and width of QRS complexes. The algorithm includes low pass, high pass, derivative, squaring and moving window integration stage. The methodology is that the ECG is passed through a low-pass and a high-pass filter in order to remove the noise from the signal. Then the filtered signal is passed through derivative, squaring and moving window integration phases. Finally a peak detection technique is applied and the R-peaks are detected. The algorithm of Pan-Tompkins is shown in figure III.

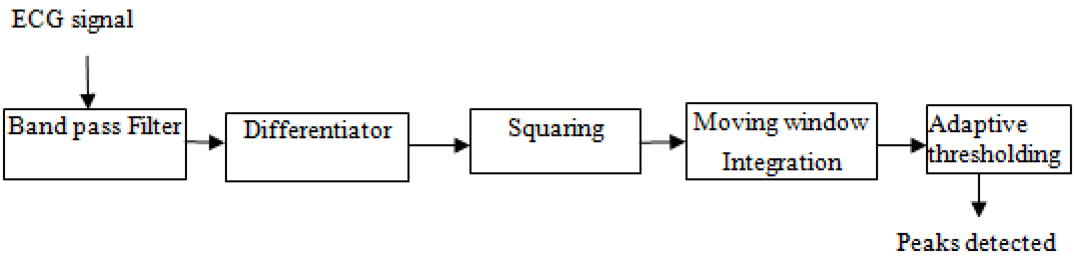


Figure III. Pan-Tomkins algorithm

Band pass Filter:

The bandpass filter, formed using low pass and high pass filters, reduces noise in the ECG signal. Noise such as muscle noise, T-wave interference and baseline drift are removed by band pass filtering. The filter should have a desirable passband to maximize the QRS energy is about 5-15 Hz. The transfer function of second-order low pass filter is,

$$H(z) = \left(1 - z^{-6}\right)^2 / \left(1 - z^{-1}\right)^2 \qquad \text{(i)}$$

and the difference equation is implemented using,

$$y(nT) = 2y(nT - T) - y(nT - 2T) + x(nT) - 2x(nT - 6T) + x(nT - 12T) \qquad \text{(ii)}$$

The design of the high-pass filter is obtained by subtracting the output of a first-order low-pass filter from an all-pass filter. The transfer function of such a high pass filter is,

$$H(z) = z^{-16} - ((1 - z^{-32})/(1 - z^{-1})32) \quad \text{(iii)}$$

and the difference equation is implemented using,

$$y(nT) = x(nT - 16\text{T}) - ((y(nT - T) + x(nT) - x(nT - 32\text{T}))/32) \quad \text{(iv)}$$

Derivative:

The next process after filtering is differentiation. Information about the slope of the QRS complex is obtained in the derivative stage. A five point derivative method is used with transfer function,

$$H(z) = (-z^{-2} - 2\text{z}^{-1} + 2\text{z}^{1} + z^{2})/8 \quad \text{(v)}$$

The difference equation is

$$y(nT) = (-x(nT - 2\text{T}) - 2\text{x}(nT - T) + 2\text{x}(nT + T) + x(nT + 2\text{T}))/8\text{T} \quad \text{(vi)}$$

Squaring Function:

The next operation is the squaring operation. Here the signal is squared point by point. The squaring process intensifies the slope of the frequency response curve of the derivative stage and helps restricting false positive caused by T-waves, as well as noise in the output of the preceding stage. The equation of operation is,

$$y(nT) = (x(nT))^2 \quad \text{(vii)}$$

Moving Window integration:

The next stage is moving window integration. The expected result is a single smooth peak related to the QRS complex for each ECG cycle. The purpose of moving-window integration is to get wave form feature data additionally to the slope of the R wave.The output of the moving-window integrator may be used to detect QRS complexes, to measure RR intervals, and to determine the duration of the QRS complex. It is calculated from,

$$y(nT) = (x(nT - (N-1)T) + x(nT - (N-2)T) + \ldots\ldots\ldots\ldots + x(nT))/N \quad \text{(viii)}$$

where N is the total number of samples in the width of the integration window. The number of samples in the moving window is important. Generally the width of the window should be approximately the same as the width of the QRS complex. If the window is simply too wide, the integration waveform will merge the QRS and T complexes together. If it is too narrow, some QRS complexes will produce several peak in the integration waveform. This will cause difficulty in subsequent QRS detection processes. The width of the window is determined empirically.

Peak Detection:

A thresholding procedure is implemented for the detection of peak of QRS complexes. Then each sample values in the ECG signal is investigated individually. The values of the ECG signal above the threshold indicate the chance of peak of the QRS complex. The sample values of the ECG signal above the threshold are then compared against adjacent sample values. If the sample value is greater than the succeeding and preceding sample value, then it can be detected as the peak of the QRS complex.

R-R Interval Estimation:

The peak of the QRS complex corresponds to R-wave. Thus the R-wave of each cardiac cycle are detected. By measuring the time interval between the adjacent R-peaks, R-R interval can be estimated.

B. ARRHYTHMIA DETECTION

Any symptom of heart attack instantaneously reflects upon the R-R interval. Based on the R-R interval the heart rate can be calculated in beats per minute (bpm). The heart rate can be computed by using the equation,

$$HEARTRATE\,(BPM) = \frac{60}{RRINTERVAL\,(SECONDS)} \quad \text{(ix)}$$

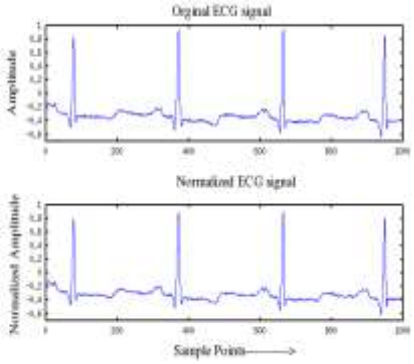
From this value obtained, analysis is done to verify whether the patient has a possibility of heart attack. The symptoms of heart attacks can be broadly classified into two types namely Tachycardia and Bradycardia. When the bpm is above 100, it is said to be a tachycardia symptom. On the other hand, if the bpm falls below 60, it is said to be a bradycardia symptom. Thus the bpm value for the normal sinus rhythm ranges between 60 and 100, i.e, normally the R-R interval should range between 600ms and 1000ms.

3. RESULTS & DISCUSSION

The ECG signals are taken from a database called MIT-BIH arrhythmia database. For simulation GNU Octave is used. Octave is an open-source interactive software system. GNU Octave is a high-level interpreted language, primarily intended for numerical computations. It provides capabilities for the numerical solution of linear and nonlinear problems, and for performing other numerical experiments [19].

Normal ECG signal

The below figures shows the simulation results of test data of normal ECG signal.



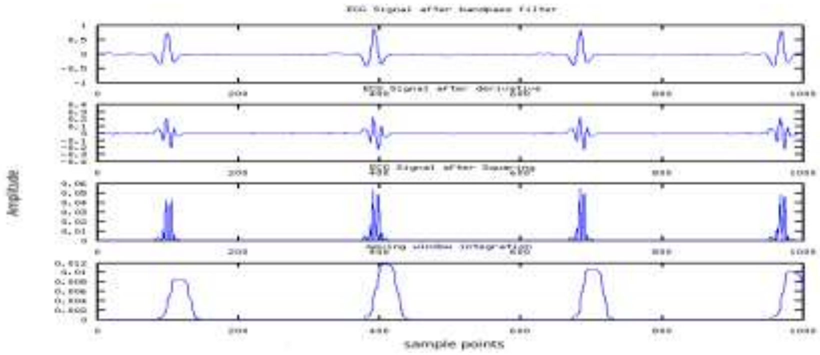


Figure IV Original and normalized ECG signal ***Figure V Pan-Tompkins algorithm implementation***

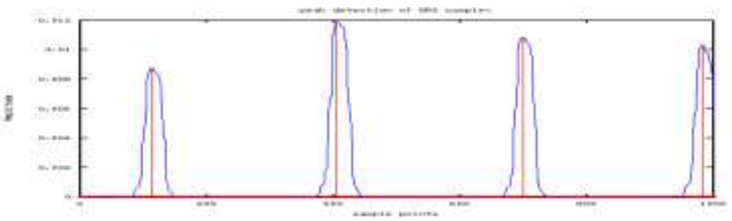


Figure VI Peak Detection

The RR interval and heart rate is then computed and result obtained is shown below for the normal ECG signal. For normal ECG the heart rate obtained is 72bpm.

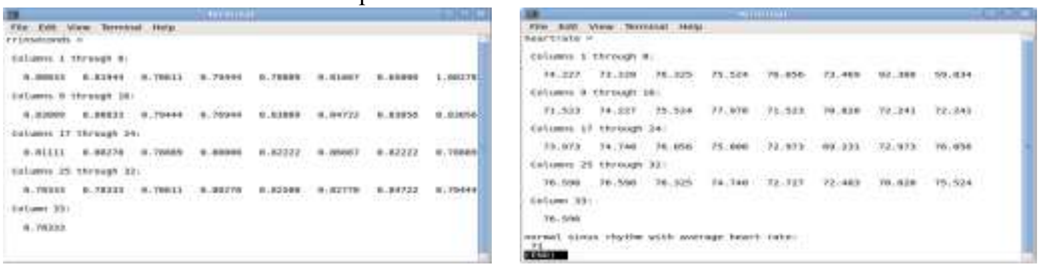
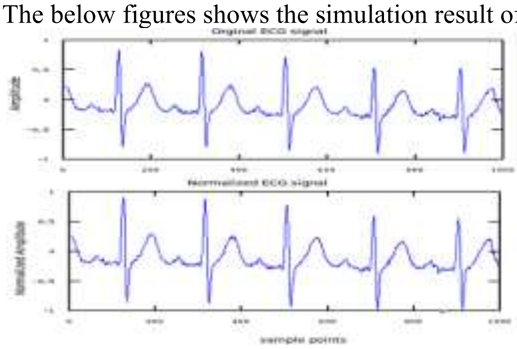


Figure VII RR interval and heart rate computation

Abnormal ECG signal (Tachycardia condition)

The below figures shows the simulation result of abnormal ECG signal specifically Tachycardia signal.



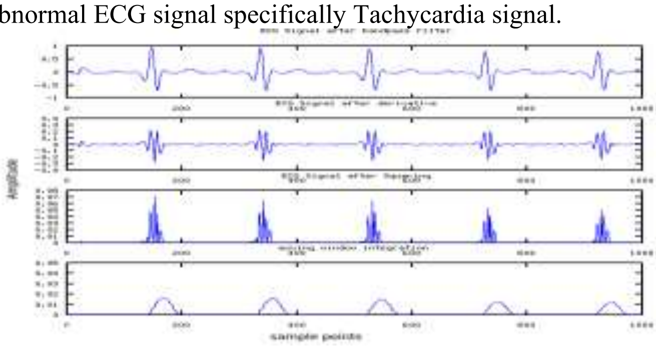


Figure VIIIAbnormal ECG signal(Tachycardia) ***Figure IX Pan-Tompkins algorithm implementation***

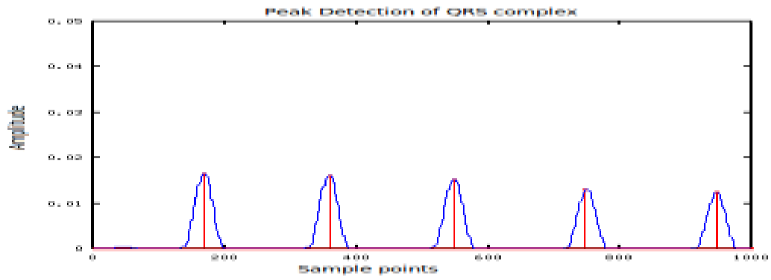


Figure X Peak detection

The RR interval and heart rate is then computed and result obtained is shown below for the abnormal ECG signal i.e. for a tachycardia condition.The obtained average heart rate is 105 bpmSince the heart rate rise above 100 bpm this condition is recognized as tachycardia condition.

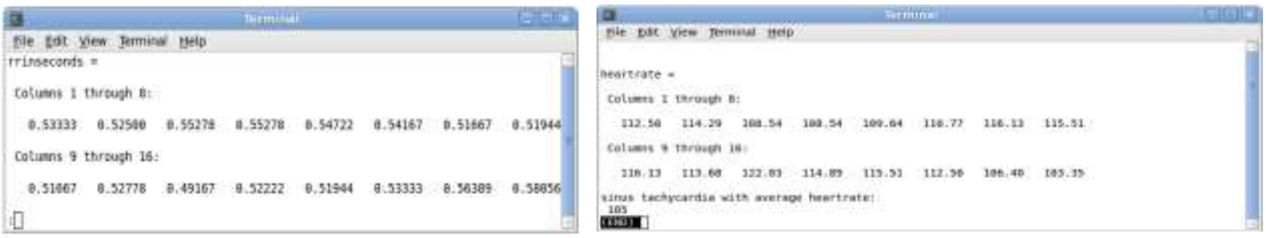
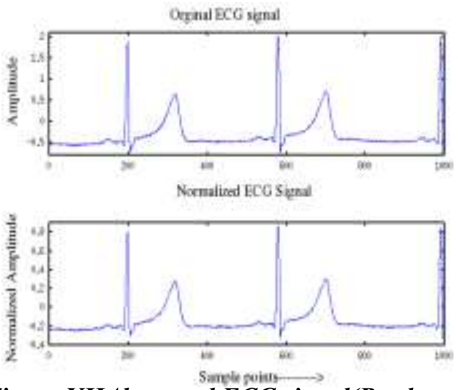


Figure XI RR interval and heart rate computation

Abnormal ECG signal (Bradycardia condition)

The below figures shows the simulation results of abnormal ECG signal specifically Bradycardia signal.



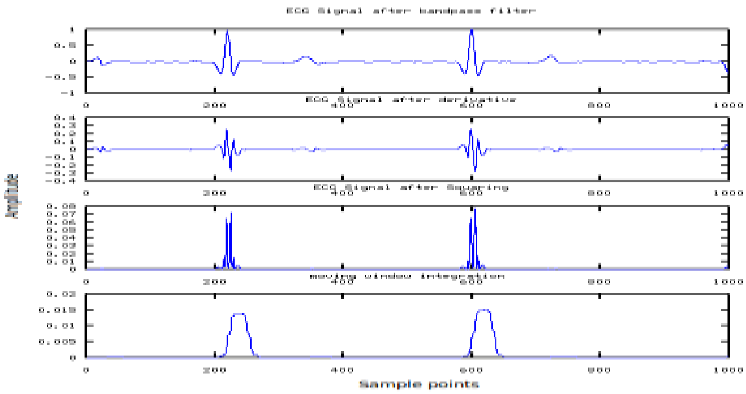


Figure XIIAbnormal ECG signal(Bradycardia) implementation

Figure XIII Pan-Tompkins algorithm

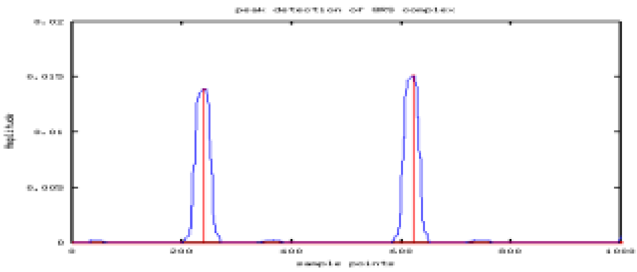


Figure XIV Peak Detection

The RR interval and heart rate is then computed and result obtained is shown below for the abnormal ECG signal ie. for a bradycardia condition.The obtained average heart rate is 55 bpm.. Since the heart rate falls below 60 bpm this condition is recognized as bradycardia condition.

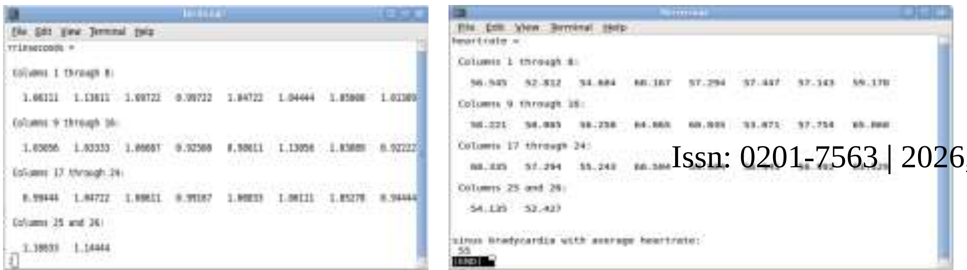


Figure XV RR interval and heart rate computation

4. CONCLUSION

Automatic detection of arrhythmias is particularly important in the diagnosis of heart diseases. In this paper, an algorithm based on time domain analysis for the detection and interpretations of different ECG arrhythmias is presented and validated with MIT-BIH arrhythmia database and achieves a high classification accuracy of 98%. This algorithm can be future implemented in a FPGA based hardware platform so as to design a portable, wearable, battery-operated, and wireless ECG systems.

REFERENCES

[1] Laszlo Szilagyi, Sandor M. Szilagyi, Gergely Ford s, Zoltan Benyo, “Quick ECG Analysis for On-Line Holter Monitoring Systems” Proceedings of the 28th IEEE EMBS Conference,USA, Aug 30-Sept 3, pp. 1678-1681, 2006.
[2] Sachin singh, Netaji Gandhi, “Pattern analysis of different ECG signal usingPan-Tompkin’s algorithm”, International Journal on Computer Science and Engineering, vol. 02, no. 07, pp. 2502-2505, 2010.
[3] M.G. Tsipouras, D.I. Fotiadisa, D. Sideris, “An arrhythmia classification system based on the RR-interval signal”,International Journal on Artificial Intelligence in Medicine, vol.33, pp. 237-250, March 2004.
[4] A. A. Tahat, “Mobile Messaging services-Based Personal Electrocardiogram monitoring system”, International Journal of Telemedicine and Applications, vol.1, pp.1-7,2009.
[5] Jiapu Pan and Willis J. Tompkins, “A real-Time QRS detection Algorithm”, IEEE Trans. On Biomedical Engineering, vol. BME-32, No.3, pp. 230- 236,March 1985.
[6] H. H. So and K. L. Chan, “Development of QRS Detection Method for Real-time Ambulatory Cardiac monitor” In proceedings 19th International conference Of theIEEE EMBS vol. 1,Chicago, USA .pp. 289-292,Oct. 30 - Nov. 2, 1997 .
[7] Natalia M. Arzeno, Zhi-De Deng, and Chi-Sang Poon, “ Analysis of First- Derivative Based QRS Detection Algorithms” IEEE Trans. On Biomedical Engineering, vol. 55, no. 2, pp. 478 – 484,Feb. 2008.
[8] Ching-Che Chung and Chen-Yi Lee, “Detection of the QRS complex, P wave and T wave in Electrocardiogram” In proc. 1st International Conference on Advances in Medical signal and Information Processing, pp. 41-45, August 2002.
[9] Myint Wai Phyu, Yuanjin Zheng, Bin Zhao, Liu Xin, “A Real-Time ECG QRS Detection ASIC Based on Wavelet Multiscale Analysis” IEEE Asian Solid-state Circuits Conference, Taiwan, November 16-18, pp.293-296, 2009.
[10] Chio In Ieong, Mang I Vai, “ECG QRS Complex Detection with Programmable Hardware” In Proceedings 30th International Conference Of the IEEE EMBS , Canada, August 20-24, pp. 2920-2923, 2008.
[11] Rizwan R. Sheikh and Imtiaz A. Taj, “Cardiac disorder Diagnosis Based on ECG Segments Analysis and classification”, In proc. 3rd Int. Con. Of the IEEE EMBS, pp.1-6, 2009.
[12] Ieong Chio In, Vai Mang Ieong Chio In, Vai Mang I, Mak Peng Un, “QRS Recognition with Programmable hardware”, IEEE Trans. On Bioinformatics and Biomedical Engineering, vol 32, pp- 2028-2032, 2008.
[13] Meng-chou Chang, Zong-xin Lin, Che-wei Chang, “Design of a system-on-chip for ECG signal processing”, IEEE Asia-Pacific Conferenceon Circuits and Systems, Tainan, vol-1, pp. 441-444, 6-9 Dec. 2004.
[14] "Atlas of Heart diseases and Stroke", WHO, Media release, 23 September 2004.
[15] Hong Liang, "ECG Feature Elements Identification For Cardiologist Expert Diagnosis", Proceedings of the 27th Annual Conference IEEE Engineering in Medicine and Biology, Shanghai, China,pp.3845- 3847,September 1-4, 2005.
[16] H.Gholam-Hosseini and H.Nazeran,"Detection and Extraction of the ECG signal parameters", Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Vol. 20, No 1, pp. 127-130,1998

[17] “Cardionetics” http://www.cardionetics.com/
[18] “Physionet” http://www.physionet.org/physiobank/database/mitdb/
[19] “Octave”, http://www.gnu.org/software/octave/