Real Time ECG Feature Extraction and Arrhythmia Detection on a Mobile Platform

Abhilasha M. Patel
M.Tech Student (Electronics)
Veermata Jijabai Technological Institute, Mumbai Maharashtra

Pankaj K. Gakare
M.Tech Student (Electronics)
Veermata Jijabai Technological Institute, Mumbai Maharashtra

A. N. Cheeran
Associate Professor
Veermata Jijabai Technological Institute, Mumbai Maharashtra

ABSTRACT
Arrhythmia means abnormal rate of heart contraction which is dangerous as it may also cause death. The work proposed in this paper mainly deals with the development of an efficient arrhythmia detection algorithm using ECG signal so that detection of arrhythmia at initial stages is possible using a smart-phone which is readily available anywhere which makes complete system mobile. Subjects for experiments included normal patients, patients with Bradycardia, Tachycardia, atrial premature contraction (APC), patients with ventricular premature contraction (PVC) and patients with Sleep Apnea. Pan-Tompkins algorithm was used to find the locations of QRS complexes and R Peaks. The algorithm to detect different arrhythmia is based on position of P wave, QRS complex, R Peak and T wave and on interval between these waves on android smart-phone. The algorithm was tested using MIT-BIH arrhythmia database. Results revealed that the system is accurate and efficient to classify arrhythmias as high overall performance (97.3%) for the classification of the different categories of arrhythmic beats was achieved. The proposed arrhythmia detection algorithm may therefore be helpful to the clinical diagnosis.

General Terms
Digital Signal Processing, Arrhythmia Detection, Biomedical signal processing

Keywords
ECG, Android smart-phone, mHealth,, eHealth, Telemedicine, Tachycardia, PVC.

1. INTRODUCTION
New emerging concepts such as “wireless hospital”, “mobile healthcare” or “wearable tele-monitoring” require the development of bio-signal acquisition devices to be easily integrated for the clinical purposes. Advancements are being made towards a cheap and effective means for health monitoring.

Heart diseases and heart failure are one of the most important reasons which cause death nowadays. Heart Disease took 631636 lives in 2006 in US which are 26 percent of whole death in US in this year [1]. According to the World Health Organization, Heart disease or cardiovascular diseases (CVD) are the number one cause of death worldwide. Of these deaths, 82% take place in low- and middle-income countries. Given their computing power and pervasiveness, it is possible for mobile phones to aid in the delivery of quality health care, particularly to rural populations distant from physicians with the expertise needed to diagnose CVD.

In this work, a new system for Electrocardiogram (ECG) acquisition and it’s processing, with wireless transmission to the Doctor or Hospital is presented. The ECG device is wirelessly connected to a smart-phone using Bluetooth. The Android based system is designed to perform real-time analysis on the ECG data to extract the different wave features and display the same on the GUI along with the ECG signal plot. Remote users have real time access to the captured information via a SMS, MMS or e-mail. This concept is intended for detecting rare occurrences of cardiac arrhythmias and ambulatory cardiac monitoring. Continuous monitoring of physical parameters is very important for improvement of the patient’s life quality.

Arrhythmia is a kind of disease which shows abnormal beats and such abnormal heartbeats may cause increase or decrease in blood pressure which can be dangerous as it may lead to paralysis or stroke or even sudden death. Cardiac arrhythmias are abnormality or disturbances in the behavior of the heart’s electrical activities. These disturbances leads to abnormality in rate and rhythm hence referred as arrhythmic. The analysis of the electrocardiogram (ECG) signal is the method available for diagnosing cardiac arrhythmias. In electrocardiograms, such arrhythmias manifest themselves as deformations or irregularities in the observed waveform. Modern techniques used for arrhythmia detection purpose based on morphology of the waveform gives accurate results for cardiac arrhythmia detection [2-5]. ECG arrhythmia waveforms can be broadly subdivided into two classes,

(1) Events: They occur as single and ectopic
(2) Rhythms: They are continuous series of one or more event types.

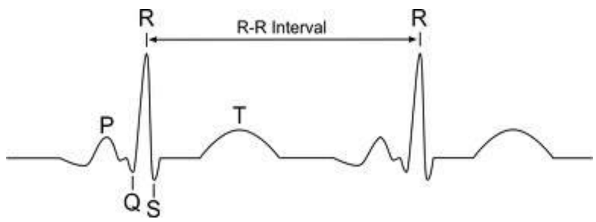

Fig. 1: ECG Waveform

As shown in figure 1 ECG is characterized by a recurrent wave sequence of P, QRS and T- wave associated with each beat. The QRS complex is the most striking waveform of all, caused by ventricular depolarization and atrial re-polarization. Once the positions of the QRS complexes are found, the locations of other waveforms of ECG like P, T waves and QT, ST segment etc. are found relative to the position of QRS, in order to analyze the complete cardiac period.

A concept – mHealth (Mobile Health) involves use of mobile device in telemedicine. It is an integration of mobile telecommunications and multimedia technologies in delivering healthcare solutions, by making use of mobile devices in collecting clinical data, delivering information to medical staff, researchers and patients. Patient’s vital signs are monitored in real time and directly provide health care through mobile telemedicine.

Android is proposed as mobile monitoring terminal. Android is one of the emerging and leading operating system for smart-phones. It provides an open source platform and also has ability to run tens of thousands of application at a time.

The analysis software can be used to diagnose the various cardiac conditions of the patient as well as other heart related signals, e.g., pulse rate. The Tachycardia, Bradycardia heart condition are common form of cardiac disease caused by fluctuations in the QRS complex of the cardiac rhythm.

The complete work is explained in the subsequent sections. Section 2 describes the architecture of the proposed system including sensor part, mobile part and server part. The details of filtering and QRS complex detection algorithm is explained in section 3. Detection of arrhythmias their characteristics and methodology used for their detection is discussed in section 4. And the summary is concluded in section 5.

2. SYSTEM ARCHITECTURE

Now as the technology is advanced, real time signal processing is possible, with inbuilt smart phone sensors and using Android as an operating system for platform development. The smart phone processes the data and monitors the patient’s wellbeing, and in case of an emergency, it can automatically inform the concern physician.

Fig. 2: System Architecture

The proposed system is made up of 3 parts namely Sensor part, Mobile Part and Server part.

2.1 Sensor Part

Fig. 3: ECG Sensor

Fig. 4: Electrode

A wearable ECG sensor can be used as a sensing device for recording ECG of the patients. A three lead ECG device with one channel input is used. Recorded data can be transferred from sensor module to mobile phone wirelessly. Different wireless communication standards such as Bluetooth [6], ZigBee [7], RFID [8], and Wi-Fi [9] can be used for this purpose. We have chosen Bluetooth module since it is readily available in most of the laptops and mobile phones.

The patient will have to place the 3 leads onto body. The ECG signal acquired from this sensor is sent to android phone via Bluetooth.

RN-800S-CB is the Bluetooth adapter which is being used with the sensor. It provides wireless, remote signal monitoring. Data is transferred using Bluetooth Serial Port Profile (SPP).

2.2 Mobile Part

The main functions that a mobile phone deploys for this particular application are:

- ECG Signal Acquisition
- EGC signal Filtering
- Measuring Important physical parameters of ECG signal
- Arrhythmia Detection
- Graphical User Interface (GUI)
- Save record of Patients in database
- Wireless Transmission to Server

ECG Signal acquisition is implemented through Bluetooth serial port on the mobile phone. Whenever an ECG frame arrives on the Bluetooth serial port, the serial port event listener on the mobile phone will call a method for retrieving the incoming frames and store them in a data buffer. The received data would be processed in buffers. This record is stored on to the phone memory.

For filtering ECG signal and measurement of different physical parameters like R Peaks, RR Interval, QRS complex etc from ECG, an algorithm “A real-time QRS Detection Algorithm” proposed by Jaipu Pan & Williams J. Tompkins [16] is used. These physical parameters help in Arrhythmia Detection.

For mobile device an excellent User Interface (UI) is designed so that even a layperson can easily operate it. A database is created in android phone that will save records of patient, so that any time it can be analyzed or resend. For this, SQLite Database is used which is supported in android.

2.3. Server Part

The ECG signal samples are transmitted to server using File Transfer Protocol (FTP). For this wireless transmission it is required to perform intelligent switching between Wi-Fi / GPRS / GSM / EDGE. At server the record of all the patients will be stored so that whenever records are required, they are reproduced. From server it is send to intended receiver i.e. to healthcare specialists either through SMS or MMS or Email.

3. FILTERING AND REAL TIME QRS COMPLEX DETECTION ALGORITHM

The most important of all the waves in the ECG waveform is the QRS complex. The accurate detection of the R-peak of the QRS complex is the prerequisite for the reliable function of ECG-analyzers [10].

There are many computer-based ECG analysis systems with enhanced capabilities for accurate diagnosis of arrhythmia. A comparative study by B.U.Kohler [11] gives different approaches used for QRS detection purpose, such as neural networks [12], filter banks [13], wavelet transforms [14] and methods based on nonlinear transforms [15]. All of these approaches are computer-based algorithms. But the implementation of a QRS detection algorithm and P peak detection on a mobile phone is a real challenge. As compared to desktop computers, mobile phones have less capable CPUs and lack support for complex mathematical operations, hence implementation of complex algorithms on mobile phones is a challenging task.

We have implemented the Pan- Tompkins real time QRS detection algorithm [16]. As shown in fig. 2 this algorithm uses filtering, differentiation, signal squaring and time averaging to detect the QRS complex.

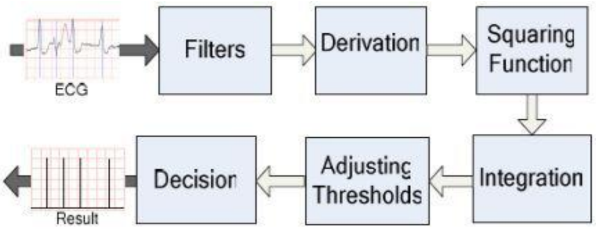

Fig. 5: Pan – Tompkins real time QRS detection Algorithm

3.1 Filtering

ECG signals from the electrodes are corrupted by various noises, such as the 60 Hz power line noise, potentials from muscular activity, and interferences from other nearby electronic devices. Hence, the signals must undergo pre-processing like filtering to remove unwanted data from being processed and misinterpreted.

This algorithm is tested on MITDB database available online [18]. Performance of this algorithm is shown on the patient with the ID 104 on Android platform.

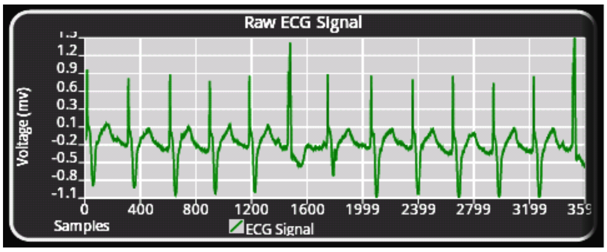

Fig. 6: Raw ECG Signal

3.1.1. Low-pass Filter

The transfer function for 2nd order low pass filter is given by:
$H(z) = (1 - z^{-6})^2 / (1 - z^{-1})^2$
$y[n] = 2 y[n-1] - y[n-2] + x[n] - 2 x[n-6] + x[n-12]$
Where the cutoff frequency is about 11 Hz and the gain is 36.

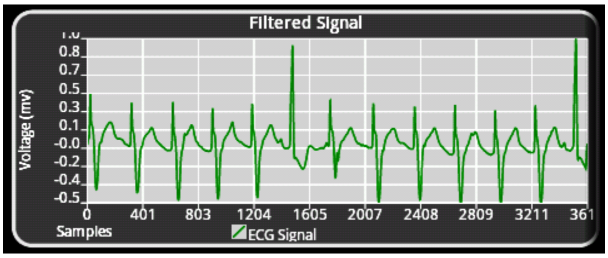

Fig. 7: Output of Lowpass filtering

3.1.2. High-pass Filter

The transfer function for the high pass filter is:
$H(z) = Y(z)/X(z) = (1 + 32 z^{-16} + z^{-32}) / (1 + z^{-1})$
The gain for this filter is 32.

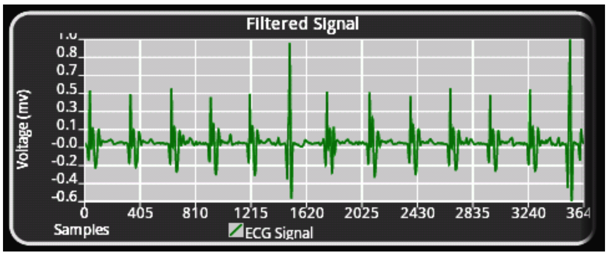

Fig. 8: Output of Highpass filtering

3.2 Differentiator

After filtering, the signal is differentiated to provide the QRS complex slope information. We used a five point derivative with transfer function:
$H(z) = 0.1 (2 + z^{-1} - z^{-3} - 2 z^{-4})$

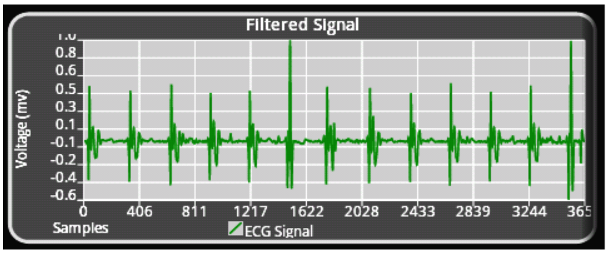

Fig. 9: Output of Differentiator

3.3. Squaring function

After differentiation, the signal is squared point by point. The equation of this operation is
$y[n] = (x[n])^2$
This makes all data points positive and does nonlinear amplification of the output of the derivative emphasizing the higher frequencies.

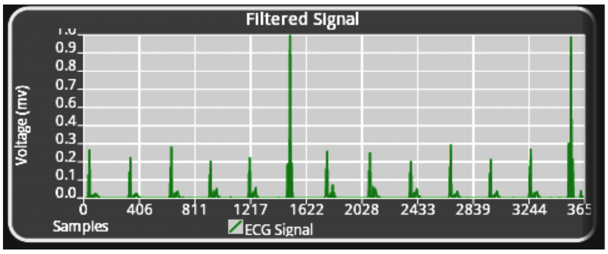

Fig. 10: Output of Squaring Function

3.4. Moving-Window Integration

The purpose of moving window integration is to obtain waveform feature information in addition to the slope of R wave. It is calculated from
$y[n] = (x[n - (N-1)] + x[n - (N-2)] + \dots + x[n]) / N$

where N is the number of samples in the width of the integration window.

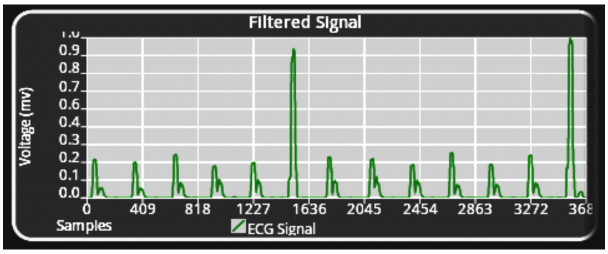

Fig. 11: Output of Integration

3.5. Threshold Adjustment and Decision

Threshold is automatically adjusted to float over the noise. Low threshold is possible because of the improvement of the Signal to Noise ratio by the Band-pass filter.

3.6. Heart Rate Measurement

After R peak detection in QRS complex the heart rate is computed in terms of BPM (bits per minute) from no of R peaks detected per minute.

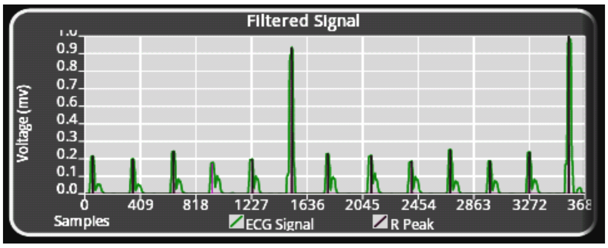

Fig. 12: Output after threshold adjustment and decision

4. ARRHYTHMIA DETECTION

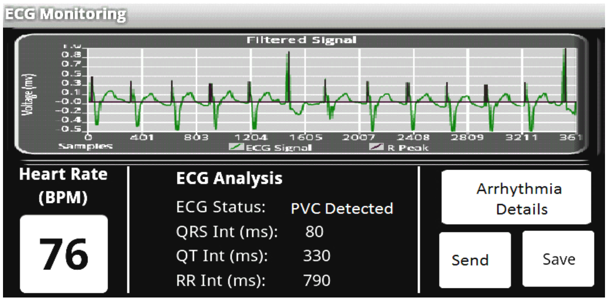

Fig. 13: Final Output with waveform feature

The analysis of the electrocardiographic (ECG) signals, especially the QRS complex as the most characteristic wave, is a widely accepted approach to study and to classify cardiac dysfunctions such as arrhythmia, tachycardia, bradycardia, Premature Ventricular Contraction (PVC) etc. Specifically, the detection of the peak of the QRS complex, or R wave, is important for diagnosis of cardiac arrhythmias, conduction disturbances, cardiac ischemia etc.

The software is able to detect the five types of arrhythmias namely Bradycardia, Tachycardia, Premature Ventricular Contraction (PVC), Premature Atrial Contraction (PAC) and Sleep Apnea. Brief explanation of these arrhythmias is given below.

4.1. Bradycardia

Bradycardia is one in which the resting heart rate falls under 60 beats per minute, though it is seldom symptomatic until the rate drops below 50 beats/min. In this condition enough oxygen is not pumped into heart. It sometimes results in fainting, shortness of breath, and if severe enough, death.

4.1.1. Characteristics:

- Rhythm – Regular
- Rate – Less than 60 beats per minute
- QRS Duration – Normal
- P wave – Visible before each QRS Complex
- P-R interval – Normal

4.1.2. Method of Detection:

If heart rate computed is less than 60 beats per minute, then it is detected as bradycardia heart condition.

4.2.Tachycardia

Tachycardia typically refers to a heart rate that exceeds the normal range for a resting heart rate (heart rate in an inactive or sleeping individual). For adult if heart rate exceeds 110 beats/min its Tachycardia condition. It can be dangerous depending on the speed and type of rhythm.

4.2.1Characteristics:

- Rhythm – Regular
- Rate – More than 100 beats per minute
- QRS Duration – Normal
- P Wave – Visible before QRS complex
- P-R Interval – Normal

4.2.2. *Method of Detection*:

If heart rate computed is more than 110, then it is detected tachycardia heart condition.

4.3. Premature Ventricular Contraction (PVC)

A Premature Ventricular Contraction (PVC), also known as a premature ventricular complex, ventricular premature contraction (or complex) (VPC), ventricular premature beat (VPB), or extra-systole, is a relatively common event where the heartbeat is initiated by the heart ventricles rather than by the Sino-Atrial node.

4.3.1. Characteristics:

- Rhythm – Regular
- Rate – Normal
- QRS Duration – Greater than 120 msec
- P Wave – Ratio 1:1
- P wave rate – Normal and same as QRS Complex
- P –R Interval – Normal

4.3.2. Method of Detection:

For this purpose QRS complex width is determined as PVCs are characterized by premature and bizarrely shaped QRS complexes usually wider than 120 msec. These complexes are not preceded by a P wave, and the T wave is usually large as P wave is buried with T wave of previous cycle.

4.4. Premature Atrial Contraction (PAC)

Another part of the atria sends an electrical impulse soon after the previous beat, causing the heart to contract earlier than expected. This is a very common occurrence in all ages and usually is not serious.

The detection of atrial premature beats is considered clinically important, since it is a sign for disturbance in the depolarization process preceding in many cases the appearance of supraventricular tachycardia, postoperative atrial fibrillation and paroxysmal atrial fibrillation.

4.4.1. Method of Detection:

The QRS Complex and R peaks within that are used for PAC detection. First condition is checked whether it is normal sinus rhythm i.e. heart rate is within 60 – 100 beats per minute, if not then tested for tachycardia heart condition. If this condition is also false then heart rate is tested for single premature heartbeat, if yes then it is checked for Premature Atrial Heartbeat.

$$\begin{cases} RR_{n-1} < 0.9\left(\sum_{i=n-7}^{n=2} RR_i\right)/5 \\ RR_n > 1.1\left(\sum_{i=n-7}^{n=2} RR_i\right)/5 \text{ and } RR_{n-1} \\ \qquad \leq \left(\sum_{i=n-7}^{n=2} RR_i\right)/5 \text{ or} \\ \frac{RR_n}{RR_{n-1}} > 1.2 \end{cases}$$

Where n is the index of tested beat

Test condition for Single Premature Heartbeat

$$\begin{cases} QRSWidthDiff_n < 5\% \text{ or} \\ QRSWidthDiff_n < 10\% \text{ and } QRSAreaDiff_n < 25\% \text{ or} \\ QRSAngDiff_n < 25^0 \text{ and } QRSAreaDiff_n < 50\% \end{cases}$$

Test Condition for Premature Atrail Heartbeat. If it is true then it is detected as PAC condition else as PVC.

4.5. Sleep Apnea

Heart rate and heart rate variability (HRV) during sleep are under the control of the autonomous nervous system. The features of sleep-related breathing disorders are repetitive cessations of respiratory flow and concomitant drops in oxygen saturation; moreover, the variation of heart rate is also obvious. Obstructive sleep apnea (OSA) is the most well-known manifestation of sleep-related breathing disorders. Sleep apnea is characterized by repetitive pauses in respiratory flow of at least 10 seconds which can occur up to 600 times in one night, and also affects HRV during sleep. In addition the repetitive apneas are accompanied by a pronounced increased variation in heart rate which is strong enough to support diagnosis.

Hence, the characteristic pattern of bradycardia and tachycardia during sleep apnea is important information [17].

4.5.1. Method of Detection:

The detected R –R beats are filtered to remove outliers linearly re-sampled at 1 Hz. Then it is locally processed using a moving 40 second window which is further smoothen using 5 second window. Hilbert transformation is then applied and median filtered using 60 second window. Apnea is detected whenever at least 15 consecutive windows are selected in the previous step, and the times of the detected apneic periods are printed.

5. CONCLUSION

With the advancements in mobile communication and egression of sophisticated wearable sensors, mobile healthcare system is developed which monitor biomedical signals (ECG) from patients. Especially the continuous recording of ECG signals improves the diagnosis and treatment of cardiovascular diseases.

The existing arrhythmia detection algorithm are computer based hence current existing systems are fixed and system proposed in this paper is portable or mobile as it is smart-phone based which makes it much useful in rural areas where it can be used very efficiently and can prove life-saving.

This system has many advantages including efficiency, accuracy, and simplicity. It is very suitable for arrhythmic detection in clinical practice. However, some exceptions from the classification rules resulting from the wide variety of individual cardiac dysfunctions are observable.

The developed algorithm is applicable for real-time operating software, e.g. for fast analysis of 24h holter ECG recordings. It could be implemented as a branch of a more complicated method for heartbeat classification.

In future, the proposed arrhythmia detection system will be able to recognize some other different arrhythmic beats and first and second degree heart block.

6. ACKNOWLEDGEMENT

We sincerely like to thank all the people who have directly and indirectly encouraged us and helped us in working out our research. Also a big thank to VJTI College from where we got complete support. Our thanks to the experts who have contributed towards development of mobile telemedicine.

7. REFERENCES

[1] American Heart Association, "Heart Disease and Stroke Statistics", Dallas, Texas, 2007.

[2] Kumar VK : A novel approach to pattern recognition in real-time arrhythmia detection. Engineering in medicine and biology society, Proceedings of the annual international conference of the IEEE 1988; 1: 7-8.

[3] Giraldo BF, Marrugat J, and Carninalti P : Design of an expert system for arrhythmia diagnosis. Engineering in medicine and biology society, Proceedings of the annual international conference of the IEEE 1992; 3, 1255-1256.

[4] Giraldo BF, Binia M, Marrugat J and Caminal P : Arrhythmia diagnosis system: validation methodology. Engineering in medicine and biology society. IEEE 17th annual conference 1995; 1: 737- 738.

[5] Dickhaus H, Gittinger J and Maier C : Classification of QRS morphology in Holter monitoring. Engineering in medicine and biology. 21st annual conference and the annual fall meeting of the biomedical engineering society 1999; 1: 270

[6] Bluetooth [Online] Available: http://www.bluetooth.org

[7] ZigBee Alliance,[Online] Available: http://www.zigbee.org

[8] RFID [Online] Available: http://www.zigbee.org

[9] Wi-Fi Alliance [Online] Available: http://www.wifi.org

[10] D. Dubin, and Rapid Interpretation of EKG's, Cover Pub Co; 6th edition, ISBN: 0912912065, 2000.

[11] B. U. Kohler, C. Hennig, R. Orglmeister, "The principles of software QRS detection", *IEEE Eng. Biol. Mag.*, 21(1), 2002, pp.42-57.

[12] Z. Dokur, T. Olmez, E. Yazgan, O.K.Ersoy, "Detection of ECG waveforms by neural networks" *Med. Eng. Phys.*, vol. 19, no. 8, 1997, pp.738-741.

[13] V.X. Afonso, W.J. Tompkins, T.Q. Nguyen, S. Luo, "ECG beat detection using filter banks", *IEEE Trans. Biomed. Eng.*, vol.46, 1999, pp.192-202.

[14] C. Li, C. Zheng, C. Tai, "Detection of ECG characteristic points using wavelet transform", *IEEE Trans. Biomed. Eng.*, (1), vol. 42, 1995, pp.21-28.

[15] S. Suppappola, Y. Sun, "Nonlinear transforms of ECG signals for digital QRS detection: A quantitative analysis", *IEEE Trans. Biomed. Eng.*, vol. 41, 1994, pp.397-400.

[16] J. Pan and W.J. Tompkins, "A real-time QRS detection algorithm," IEEE Trans. Biomed. Eng., vol. BME-32, pp. 230-236, 1985.

[17] Penzel T, Kantelhardt JW, Grote L, Peter JH, and Bunde A: Comparison of detrended fluctuation analysis and spectral analysis for heart rate variability in sleep and sleep apnea. IEEE Trans. Biomed. Eng. 2003; 50: 1143-1151

[18] MIT Database [Online] Available: http://www.physionet.org/physiobank/database/mitdb