

HRV Analysis using Electrocardiographic Signal Processing

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ABSTRACT

The main objective of the paper is to display results acquired through HRV analysis using Electrocardiogram (ECG) signal processing and analysis. ECG Signal is acquired from patient's body. This signal is fed to instrumentation amplifier and Right Leg drive is used to provide feedback to the circuit. This technique improves the signal quality and strength. ECG signal processing is done using morphological and digital filters. The analog ECG signal is acquired into Computer based Analytical tool using inbuilt PC sound card. The Computer based Analytical tool is used as a tool in order to carry out digital filtering. It is well equipped to calculate heart beat to beat interval and HRV parameters which facilitate HRV analysis. The parameters which are obtained are then displayed on Graphical User Interface (GUI) for further reference.

Keywords

Electrocardiogram (ECG), heart rate variability (HRV), Graphical User Interface (GUI), Right leg drive

1. INTRODUCTION

ECG is a continuous record of voltage changes as a result of physiological changes occurring in the heart muscles. It is predominantly recorded by placing electrodes at specific location on the subject's body. ECG plays a vital role in the diagnosis of heart related problems and is used by the doctors for identification of physiological and pathological phenomena. Apart from these usual methods another new aspect of studying, determining and understanding an individual's health is the measurement of HRV. HRV is a measure of the time intervals between consecutive heartbeats (measured in milliseconds). It has been recognized that for good health these intervals should vary in what appears to be a random and chaotic manner. There are different methods of evaluating HRV. The two most common, as recommended by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, are Time Domain Methods and Frequency Domain Methods. Of the different methods of recording HRV, the most stable and the measure of variability itself is SDNN; Standard Deviation of Normal to Normal Heart Beats. HRV is not the pulse rate or blood pressure.

2. THE SYSTEM MODEL

Our system can be categorized in 5 parts as shown in figure 1.

2.1 Input

Input is the electrocardiogram signal which is amplified. Input to the system is taken from patient's body by placing AgCl electrodes at specific locations.

2.2 Instrumentation Amplifier

The electrocardiogram signal obtained from the subject's body is in millivolts. In order to process the signal, it is necessary that the signal be amplified. This signal is fed as differential input into instrumentation amplifier AD620 which amplifies the signal.

2.3 Right Leg Drive

The right leg drive is basically a technique in which the right leg act as a reference electrode. This technique helps to improve (Common Mode Rejection Ratio) CMRR. It acts as a feedback by taking common mode voltage of the body and feeding it into the right leg thus the differential signal generated from left and right hand is improvised by noise elimination. It also helps in eliminating 50 Hz power supply noise.

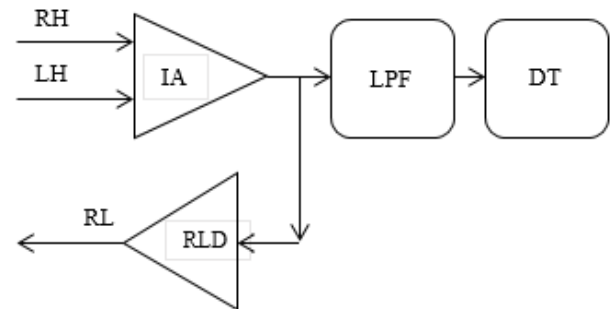


Figure 1. Block diagram of HRV Analysis System

Where RH is Right Hand, LH is Left Hand, RL is Right Leg, RLD is Right Leg Drive, LPF is Low Pass Filter and DT is Deployment Tool.

2.4 Filtering

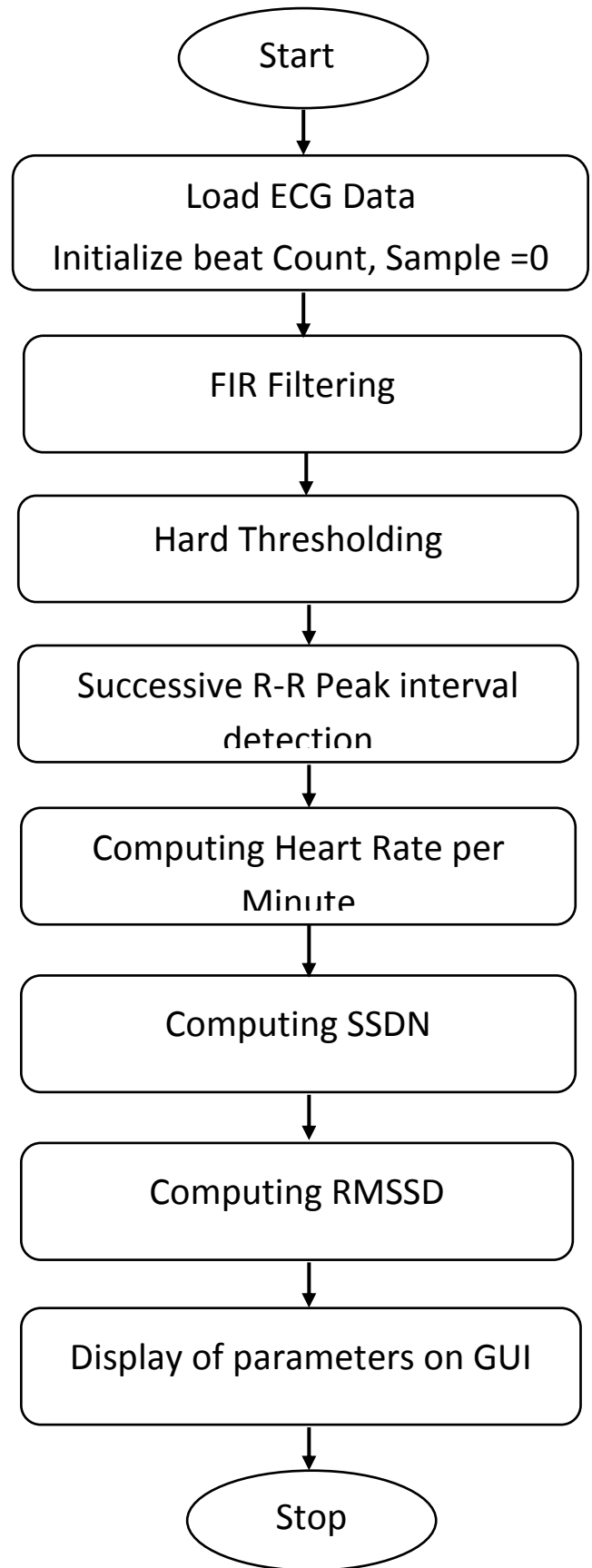
ECG signal being highly susceptible to noise interference has to be filtered using analog filter in order to reduce artefacts. Filtering reduces numerous frequency harmonics of the ECG signal but in the absence of filtering it becomes difficult to acquire the signal. Moreover, the R-peak detection being the main objective behind signal acquisition, low pass filtering can be used as it seldom alters the R-R peak detection mechanism.

2.5 Analytical Tool and GUI

The objective behind designing a GUI based system is to make the system user friendly. In the absence of GUI the user will have to keep executing the processing program through command window. The objective of creating a deployed tool is to provide memory conservation. The main aim of the GUI is to design an advanced tool for studying the variability of heart beat-to-beat interval. The designed GUI aims to provide variety of different analysis options and easy to use interface. The software is feasible enough so as to make it suitable for researchers as well as clinicians with varying premises. Objective of the software is highly oriented towards the analysis of normal human HRV. The deployed tool makes it simpler and convenient to acquire and process ECG signal. The same can be achieved by using minimal memory and operating system considerations so that the GUI doesn't employ and require its basic programming software installed. The GUI predominantly works on the basic principle of HRV analysis, which is to examine the sinus rhythm modulated by the autonomic nervous system. Therefore, one should technically detect the occurrence times of the SA-node action potential. This is however, practically impossible and thus the fiducial points for the heart beat is usually determined from the analog acquired ECG signal. In the deployed tool the recorded signal is analyzed by processing the ECG signal, to obtain QRS complex occurrence. Once the QRS complex occurrence times have been estimated, the HRV time series can be derived. The HRV time series is used to calculate and compute time domain parameters. Basic components like heart beat to beat interval and acquired ECG signal is also displayed in the GUI.

3. ALGORITHM

Deployed tool performs signal processing and analysis on the acquired ECG signal to display the acquired results as output. Processing done inside the deployed tool can be understood by considering the following flow chart:



Flow chart:

The GUI processing steps of the flow chart can be explained in detail as follows:

3.1 ECG signal acquisition

The analog ECG signal is acquired into the GUI by using 16-bit ADC and 1 channel input. The signal is sampled at 1000 Hz frequency. ECG signal has a range of 0.05 to 150 Hz and hence sampling done at $f_s = 1000$ Hz in unnecessary considering Nyquist criteria, hence the signal is then down sampled and sampling frequency (f_s) is made 100 Hz.

3.2 Digital Filtering

Digital filtering is done using a Finite Impulse Response (FIR) filter. The filter used is of 100th order and filtering uses a Chebyshev window. IIR (Infinite Impulse response) filters can also be used in place of FIR filters. However FIR filters are preferred because of their stability and greater noise removal capability due to higher order implementation.

3.3 Hard Thresholding

The filtered signal is subjected to hard thresholding in order to find out R-peaks in the signal. As the signal duration is only of 60 seconds, hard thresholding provides reliable and accurate results. In case, the signal to be analyzed spreads over a large duration of time then soft thresholding is preferred due to baseline wandering. Corresponding sample numbers of the acquired R-peaks are stored in a vector in order to acquire the respective sample numbers containing the R-peaks.

3.4 R-R peak interval detection

R-R peak interval is the time elapsed between consecutive R peaks. The figure 2 shown below illustrates the same.

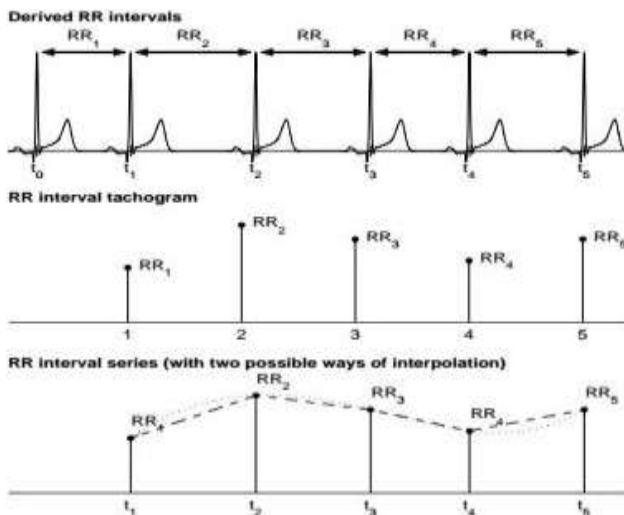


Figure 2. R-R peak intervals

By taking the difference between consecutive samples of the detected R-peaks, R-R peak interval can be computed. RR peak interval obtained is stored in seconds using the formula: R-R peak interval = (no. of samples between 2 R-peaks) / (sampling frequency of the signal). Thus, the obtained RR peak intervals for N number of R peaks is N-1. In this way, a vector of N-1 columns known as HRV vector can be obtained. This vector contains the train of RR peak intervals

which can be used to calculate heart rate variability. The obtained HRV vector can be used for computing time domain and frequency domain parameters. HRV vector is plotted in order to understand variability in R-peak to peak interval.

3.5 Computing Time Domain Parameter

The time-domain methods are the simplest to perform analysis since they are applied straight to the series of successive RR interval values. The most evident such measure is the mean value of RR intervals (RR) or correspondingly, the Heart Beats per Minute. In addition, several variables that measure the variability within the RR series exist. Following are the time domain parameters which are computed in the deployed tool by implementing the following formula for each of the parameters respectively: The standard deviation of normal to normal heart beats (SDNN) is defined as

$$SDNN = \sqrt{\frac{1}{N-1} \sum_{j=1}^N (RR_j - RR)^2}$$

Where RR_j denotes the value of j th RR interval and N is the total number of successive intervals. The SDNN reflects the overall (both short-term and long-term) variation within the RR interval series. For stationary RR series $E\{\Delta RR_j\} = E\{RR_{j+1}\} - E\{RR_j\} = 0$ and SDSD equals the root mean square of successive differences (RMSSD) is given by

$$RMSSD = \sqrt{\frac{1}{N-1} \sum_{j=1}^{N-1} (RR_{j+1} - RR_j)^2}$$

Where,

RR_j = value of j th RR interval

N = total no. of successive interval

3.6 Heart Beats per Minute Computation

Heart Beats per Minute = $(60 \times F_s) \div N$

Where,

F_s = Sampling Frequency

N = R-R peak interval

4. RESULTS

Following are some of the numerous results that were obtained after system implementation. The figures below display recording of a few subjects. The top most Graph displays recorded ECG signal. Y-axis shows electrical activity and the X-axis shows number of samples. The next graph shows heart rate variability. The parameters indicated to the right are time domain HRV parameters along with beats per minute (BPM) and beats per second (BPS). It has to be noted that the recordings were taken when the subjects were breathing steadily. Another important point to be considered is that the recordings have been taken only for 60 seconds. In order to generate more conclusive results the data can be recorded for five minutes or 24 hours. Longer time duration of the recorded signal will produce better conclusive and reliable deductions. Following are a few conclusions that can be drawn by examining the results which are mentioned in the caption below the respective images.

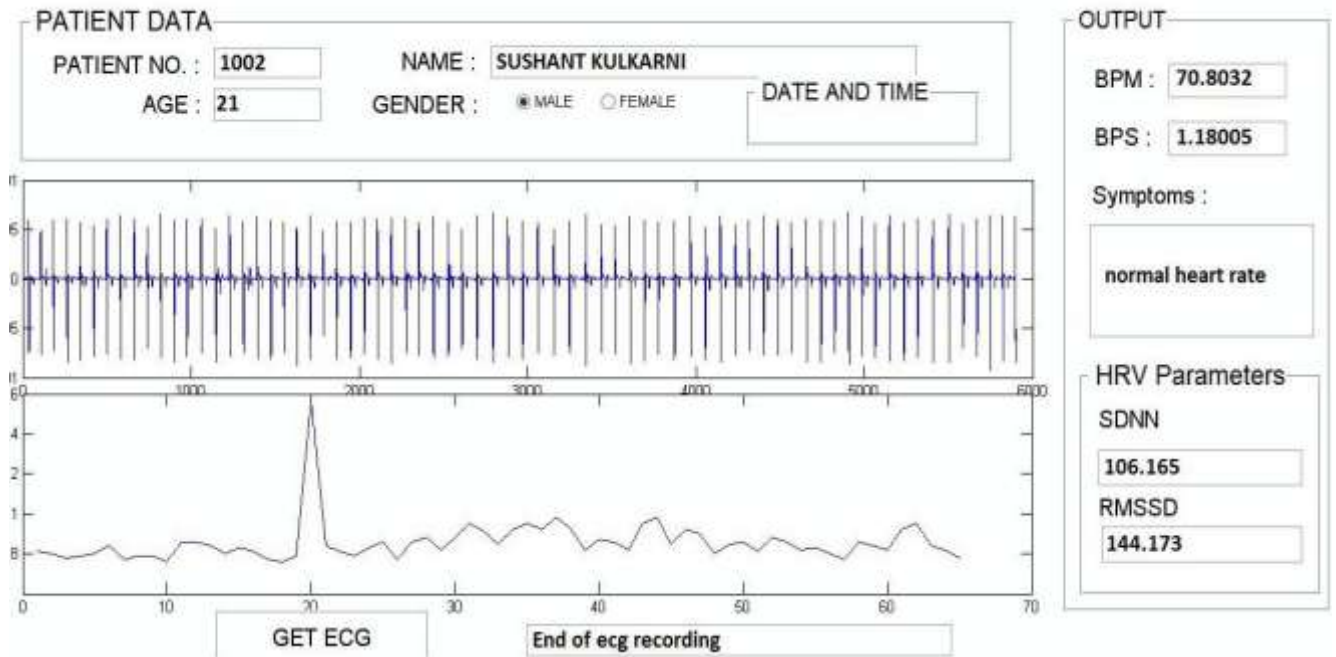


Figure 4. Result 1 obtained on GUI displays ECG signal in the first plot and moderate HRV in the second plot

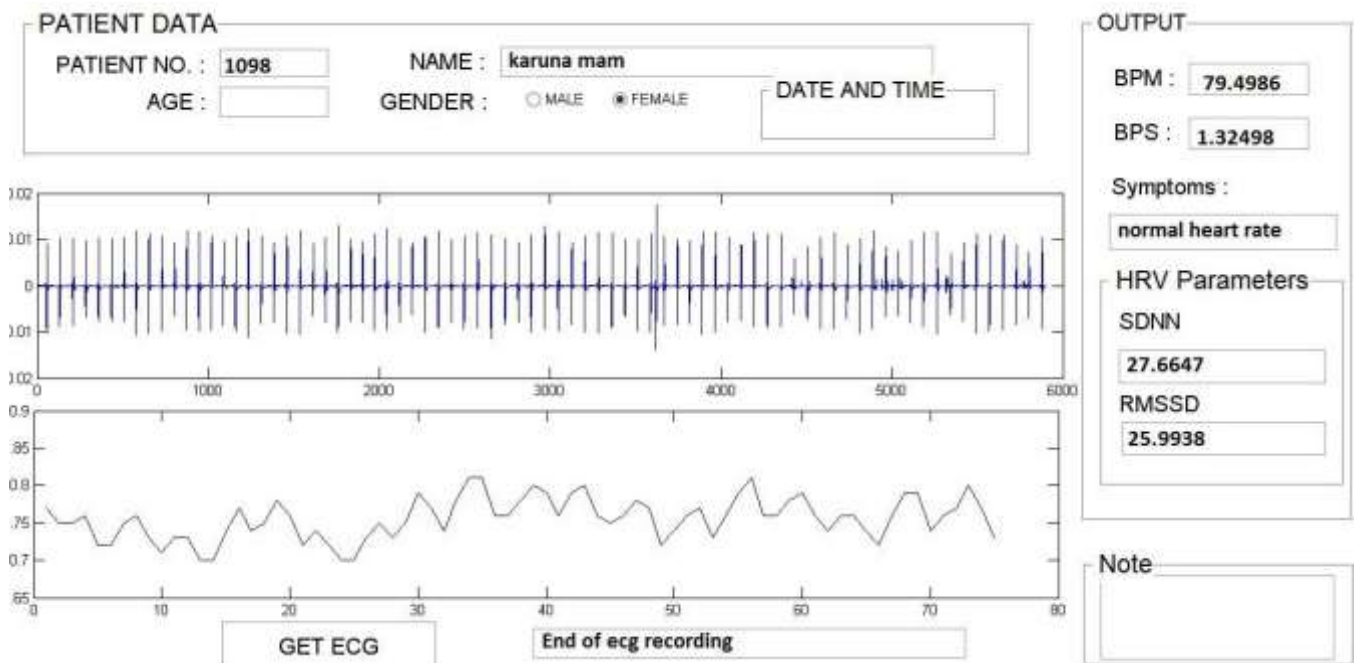


Figure 5. Result 2 obtained on GUI shows ECG signal in the first plot and second plot shows high variations in the heart rate

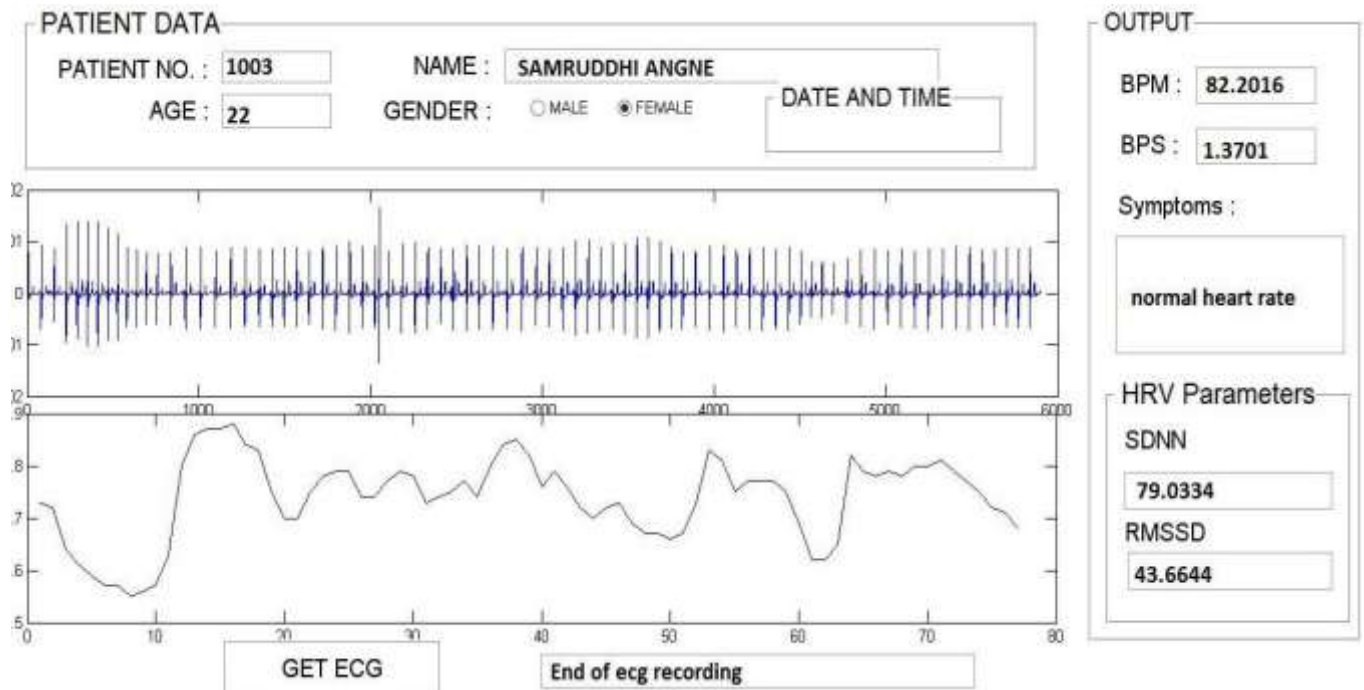


Figure 6. Result 3 obtained on GUI shows irregular heart rate variations in the second plot

5. CONCLUSION

The analog circuit implemented using instrumental amplifier as well as filters and right leg drive for noise minimization successfully extracts ECG signal from the subject's body, when electrodes are placed at strategic positions. The signal acquired in is filtered and processed further to successfully acquired HRV train, which can be used to compute time domain HRV parameters like SSDN, RSSDN, beats per minute, etc. in the Computer based Analytical Tool. The acquired and derived parameters are successfully presented in the GUI output. Moderate HRV in the 1st result is not a very conclusive parameter for health analysis. However, varying and erratic HRV, as shown in result 2 and result 3, can be considered as a sign of healthy individual. The GUI output can be successfully saved on the personal computer as an image file, which further reduces memory requirement.

6. FUTURE SCOPE

In this project ECG is acquired using 3 lead electrode scheme due to cost and hardware limitation. A better ECG signal wave can be obtained by using 12 lead electrode scheme, for having a better GUI Display. In this paper, the results displayed are pertaining to HRV analysis in time domain, however frequency domain analysis equips researcher or practitioner with highly reliable data that can further facilitate accurate prognosis. Frequency domain analysis will require software modifications to include additional algorithms. Data examined in this project is only for a short duration due to time constraints; however conventional recordings can be done for higher period of time. Larger duration of recordings can provide better conclusive results. GUI can be made further user-friendly by segregating the display further and providing selectable icons. Data uploading network protocols which provide faster image uploading can be used. Project can be implemented on large scale.

7. DRAWBACKS

The acquisition circuit can be made more robust. The output of the analog circuit should have low amplitude otherwise it may lead to damage of sound card in the long run. Down sampling the signal causes decimation of the ECG signal and leads to aliasing in the frequency domain. Aliasing can be avoided by digitally implementing an anti-aliasing filter.

8. ACKNOWLEDGMENT

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9. REFERENCES

- [1] L. Cromwell, in Biomedical Instrumentation and Measurements, Berlin, Pearson Education, 2010
- [2] R. M. Rangayyan, "Biomedical Signal Analysis," in A Case-Study Approach, Singapore, John Wiley & Sons (Asia) Pte. Ltd., 2002.
- [3] R. S. a. M. E. V. Valkenburg, in Design of Analog Filters, Oxford, 2009.
- [4] Khorovets, What is An Electrocardiogram?" The International Journal of Health, vol. 1, no. 2, 2000
- [5] Nouredine Belgacem , Said Assous, FethiBereki-Reguig , matlab-based gui for ecg signal acquisition and analysis 2011."7th International workshop on systems, signal processing and their applications (Wosspa)", Algeria, pp87-90-2011
- [6] U. Rajendra Acharya , K. Paul Joseph, N. Kannathal, Choo Min Lim, Jasjit S. Suri," Heart rate variability: a review" , Med Bio Eng Comput (2006)

- [7] Mika P. Tarvainen, Juha-Pekka Niskanen, “Kubios HRV”, [Online] Available: http://www.kubios.uef.fi/media/Kubios_HRV_2.2_Users_Guide.pdf [Accessed Mar 10, 2015]
- [8] Low Cost Low Power Instrumentation Amplifier”, [Online] Available: <http://www.analog.com/media/en/technical-documentation/data-sheets/AD620.pdf> [Accessed Nov.14, 2015]
- [9] Ajay Bharadwaj, Umanath Kamath,” Accurate ECG Signal Processing”, [Online] Available: <http://www.cypress.com/?docID=28762/> [Accessed Jan.15, 2015]
- [10] LM741 operational Amplifier”, [Online] Available: <http://www.ti.com/lit/ds/snosc25c/snosc25c.pdf> [Accessed Nov.14, 2015]
- [11] Scott W. Harden,” DIY ECG Machine on the Cheap”, [Online] Available: <http://www.swharden.com/blog/2009-08-14-diy-ecg-machine-on-the-cheap/> [Accessed Dec09, 2014]