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Design of Bioamplifier for Recording of Low Frequency Cardiac Electrophysiological Signals

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Abstract—*This paper focuses on the design of an inexpensive and effective ECG recorder along with the development of algorithms for the clinical analysis of the acquired data. To achieve this system, National Semiconductor's LM324 is used for the acquisition of the analog cardiac electrophysiological signal in the form of an audio signal. The signal is acquired and recoded digitally in the acquisition software, noises are filtered out with the help of digital filters which also helped in keeping the hardware design simple and cheap. For the analysis purpose an algorithm is developed on the python platform to derive HRV parameters from the recorded ECG signal. This paper evaluates the performance of the designed hardware.*

Keywords*: Hardware design, Acquisition, National Semiconductor's LM324, ECG recoding, HRV analysis.*

1. INTRODUCTION

Electrocardiogram or ECG is the graphical representation of the heart's electrical activity of depolarization and repolarization of the cardiac muscles and it is acquired non-invasively from the surface of the skin with the help of electrodes placed in an appropriate lead configuration. A conventional ECG comprises of P wave, QRS complex and T wave of which QRS complex is of utter importance. QRS complex is the most unique event in an ECG, it signifies the depolarization of the ventricles which comprises of greater muscle mass and hence high amplitude is generated. QRS complex is imperative for the calculation of R-R interval which helps in investigating the heart rate variability (HRV) and other clinical parameters [5].

Cardiovascular diseases are major cause of death around the world. An effective way to fight these disease is to detect it at a premature stage and averting it from happening which can be achieved by regular ECG checkup [1 - 6].

Cardiac electrophysiological signals are the low frequency signals generally laying within the range of 0.5Hz to ≥ 50Hz. An unprocessed ECG signal is mixed with noises of higher frequency and must be filtered before calculation or analysis of clinical parameters.

Most of the analysis is produced in the graphical form to help the clinician to draw conclusions just by looking at them.

Noise Handling and Front End Circuit

For an ECG recorder, any noise association with ECG waveform will limit the resolution for further analysis. Hence the front end design is of utter importance. The ECG signal acquired from the skin is weak usually ranging from 0.5mV to 5mV while the magnitude of the coupled noise is ±250mV. Most of the ECG noises are associated with the following:

a) Large DC offset resulting from electrode-skin contact.
b) The system can pick 50Hz line frequency at any point.
c) Motion artifact arising due to the change in impedance and capacitance sensed by the electrode.
d) Large common mode noise resulting from the potential difference between electrode and ground.

These noises can be treated on board by adding band pass and notch filters to the front end design though it will add complexity in the circuit. Despite of the presence of notch filter in the design, acquired signal is susceptible to 50Hz line frequency. So, a smart approach to remove these noises is digital filtration of the signal which also helps in retaining the simplicity of the circuit. For digital filtration the analog ECG signal must be converted to digital form.

An analog ECG front end circuit is designed such that it can acquire the signal from the skin with the help of electrodes. Figure 1 shows a simple circuit for acquiring ECG signal. Here, single operational amplifier i.e. National Semiconductors LM324 is used which is having large dc voltage gain of 100 dB, wide bandwidth of 1MHz, internal frequency compensation, low power consumption and many more features that helped in keeping the design simple and reliable. Next section describes how the signal is acquired from the skin along, noise filtration and processing of the signal [3].

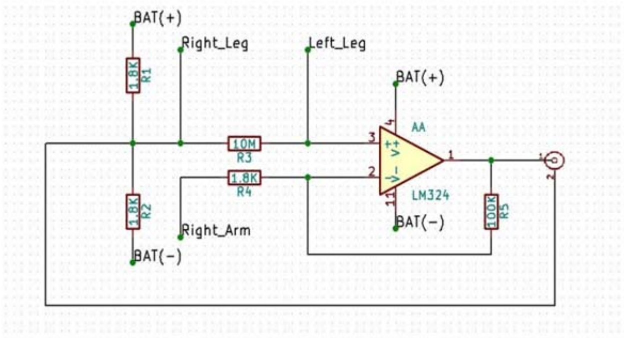

Figure 1. ECG front end circuit.

2. ECG SIGNAL ACQUISITION

The data is acquired through the disposable electrodes which is placed on the skin in lead II configuration. Right leg serves as reference in all limb lead configuration. In the absence of right leg the signal picks up more noise and also P wave is absent under such condition. On-board filtration is not done in this case just to keep it simple and inexpensive to reproduce. The signal is acquired as an audio signal laying within the range of 0.5Hz to 50Hz, which can be easily processed by any audio signal processing software in this case GoldWave software is used for audio processing. The output of the circuit is connected to a 1/8" audio jack also referred as 3.5mm jack which is inserted to the line-In of the pc, the sound card of the pc automatically convert these signals to digital form. Hence the signal is digitized and fed to the GoldWave software where it is recorded and saved in a sound extension file .snd or .wav. Figure 2 shows the unprocessed data recorded from the skin.

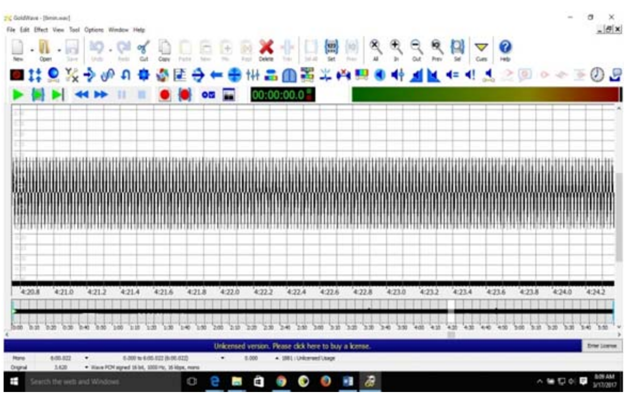

Figure 2. Unprocessed data recorded in GoldWave.

The signal is processed in the GoldWave software by applying a low pass filter having 30Hz as cutoff frequency. The sound signal is further amplified digitally and the resulting signal with prominent ECG waveform is achieved and which is shown in figure 3. These recorded signal can be used for analysis purpose.

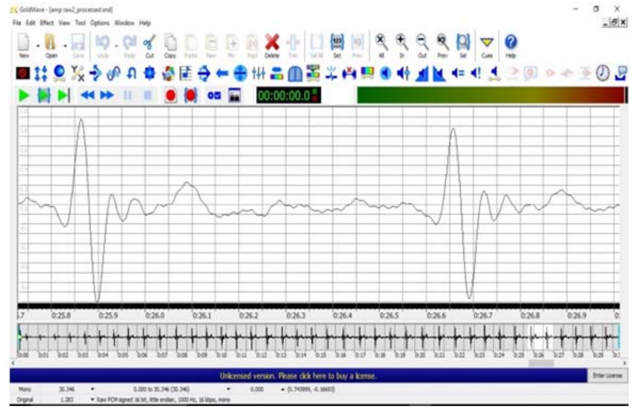

Figure 3. Processed data after applying 30Hz low pass filter.

For evaluation purpose the same raw data is processed with MATLAB with a 2nd order band pass filter having f_L = 0.001Hz and f_H = 20Hz. A similar waveform, shown in figure 4, is obtained.

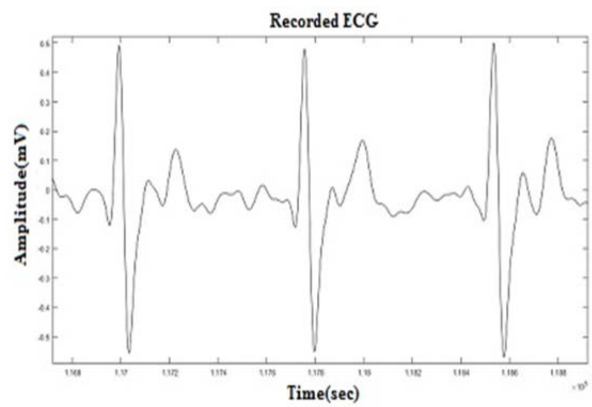

Figure 4. Data processed in MATLAB.

The signal is also acquired by National Instruments DAC USB 6004 and digital output is provided to the LabView software. Figure 5 shows the QRS complex acquired by LabView in the real time.

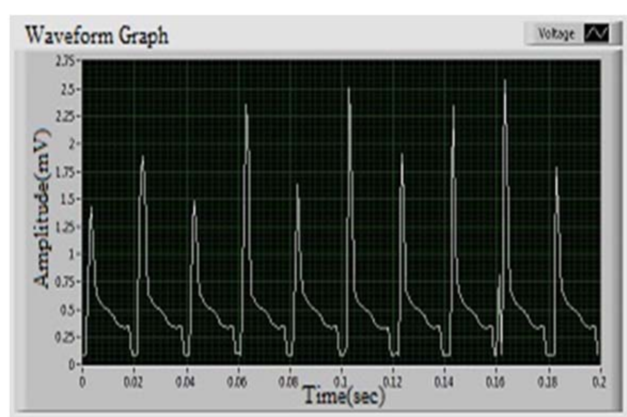

Figure 5. Real time QRS complex acquired in LabView.

3. ANALYSIS OF THE RECORDED DATA

For the analysis of the recorded data a python program is developed. The python platform is a free and open source programming language. Python interpreters are available in most of the operating systems. The script written for the HRV analysis is developed in python v.2.7.13 along with numpy, matplotlib, scipy, pyqrgraph and PyQt4 packages [2].

The program reads the processed .snd files obtained from the GoldWave software and searches for the peaks and determine the R-R intervals which helps in calculation of different clinical parameters. Figure 6 shows the peaks detected by the python script.

The R-R interval helps in calculating heart rate which is the speed of the heartbeat measured by the number of contractions of the heart per minute measured in beats per minutes (bpm). By plotting the inverse of the R-R intervals, heart rate is plotted as a function of time. The normal resting adult human heart rate ranges from 60–100 bpm. Figure 7 shows the heart rate of the acquired data.

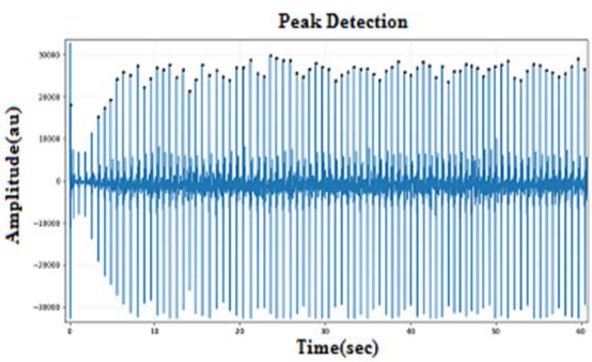

Figure 6. Peaks of the acquired data.

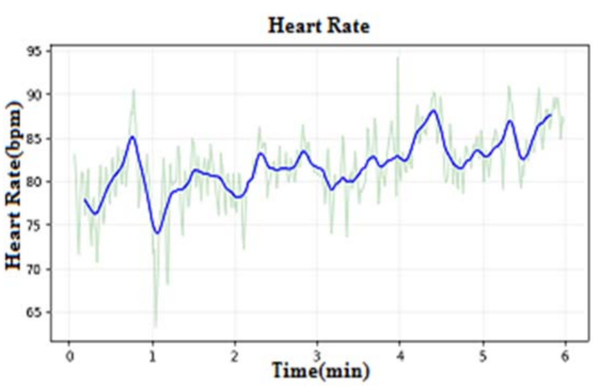

Figure 7. Heart rate of the acquired data.

Inter-beat R-R interval is the time interval between consecutive hearts beat measured in ECG from one QRS complex to the next QRS complex. Figure 8 shows the Inter beat R-R interval of the acquired ECG data.

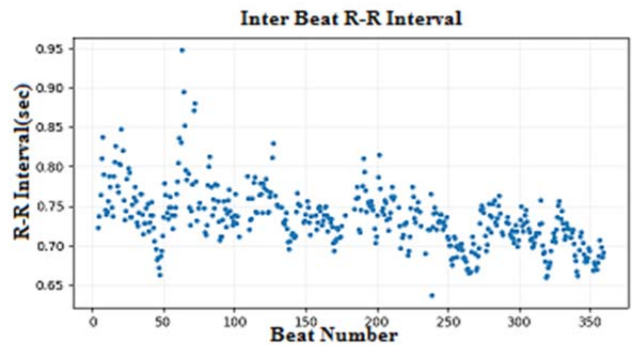

Figure 8. Inter-beat R-R interval.

The new way of studying biomedical signals is the non-linear method of analyzing the bio-signals, it can be used for non-stationary data interpretation. Poincare is the plot of R-R interval to the next R-R interval. Figure 9 shows the Poincare plot of the acquired data.

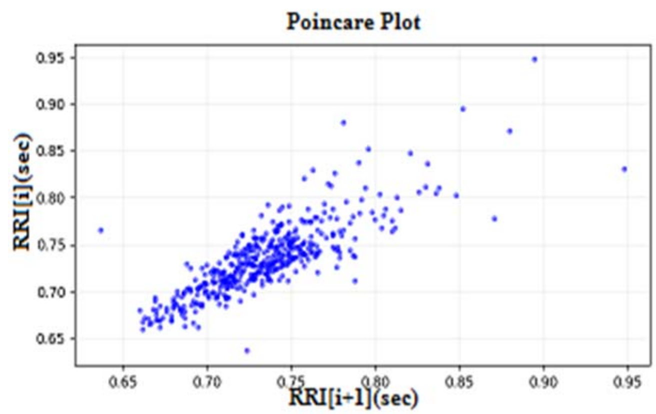

Figure 9. Poincare plot.

4. CONCLUSION

An inexpensive and miniaturized ECG recorder has been designed and analysis of the data has been attained by the python program developed exclusively for the analysis of the recorded ECG data. The recorder provided a reliable ECG signal to the program which helped in drawing conclusions about the heart rate variability (HRV) of the patient. The total cost for building the prototype came out to be only 80 INR, the acquisition software is available for free and the analysis program was built on the python platform which is also available for free. All analysis is produced in graphical form to help the clinician to draw diagnostic conclusions easily.

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