

Acquisition of ECG Signal using EPIC Sensor

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ABSTRACT: ECG, Electrocardiogram provides valuable information about wide range of cardiac disorders. This paper describes the design of ECG recording system based on the application of EPIC sensor along with dedicated instrumentation and signal conditioning system. The ECG signal recorded using this novel sensors provides reliable ECG data that is obtained relatively with ease without requiring gels or other contact enhancing substances. Waveform captured with EPIC sensors are comparable to that of recorded with conventional Ag-AgCl electrodes. The signal recorded using the present system has been processed with MATLAB for signal enhancement. This paper also contains algorithms for extraction of basic ECG features like QRS complex duration, P&T wave intervals, average heart rate etc.

KEYWORDS: EPIC(Electric Potential Integrated Circuit), ECG(Electrocardiogram), Ag-AgCl Electrodes, MATLAB

I. INTRODUCTION

Electrocardiogram is the recording of the electrical activity of the heart which is a quasi periodical, rhythmically repeating signal, synchronised by the function of the heart. This generated signal is detected as voltage difference between an electrode pair, called Lead.

Electrodes presently in use for routine recording of ECG signal are surface electrodes such as Limb electrodes and pre-gelled disposable electrodes. Impedance of limb electrodes is nearly 2-5 K Ω when measured at 10Hz. It is generally used during surgery because the patient's limbs are relatively immobile, but not suitable for use in long term patient monitoring. They are reusable and require external gel for skin-electrode preparation. Although wet electrodes have features that can help in reducing the possibility of artifacts, drift and baseline wandering, it can cause skin irritations and allergic reactions due to toxicological issues of the gel in long-term treatment[1]. In addition, the quality of the signal is also reduced as the gel dehydrates during prolonged use, and replacement of the gel is typically infeasible[5]. Moreover, in conductive electrodes, shifts in electrode position at electrode-skin interface appear as baseline drift, particularly when the subject moves. Another type of electrodes that can be used for ECG are dry electrodes. Figure 1 shows pre-gelled disposable electrodes and EPIC sensor. In this paper, we demonstrate the use of EPIC sensors which are dry capacitive electrodes for acquisition of ECG and subsequently compare the resultant waveform with that obtained using pre-gelled disposable electrodes.

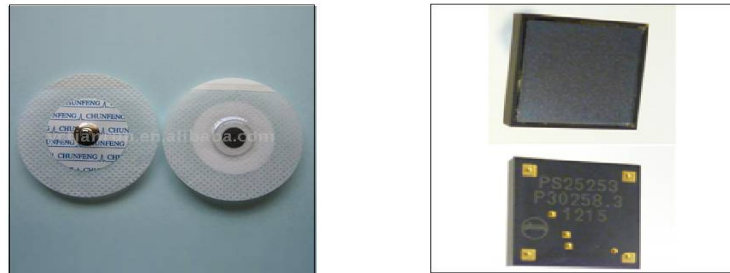


Figure 1. pre-gelled disposable electrodes(left) and EPIC sensors(right)

II. EPIC SENSORS

EPIC, a non contact electrometer, having no direct DC path from outside world to the sensor inputs, was developed by Plessey Semiconductors. Figure 2 represents the block diagram of the typical EPIC Sensor. The electrode is protected by a capping layer of a dielectric material to ensure that the electrode is isolated from the body being measured. The device is AC coupled with frequency performance, with 20KHz as lower corner frequency and 0.2Hz as upper corner frequency. This paper proposes a method of ECG acquisition using PS25253 EPIC Sensors. By using active feedback techniques, the sensor reduces the effective input capacitance($\sim 15\text{pF}$) of the sensing element and increases the input resistance($\sim 20\text{G}\Omega$), thus giving a frequency response suited for both diagnostic and monitoring ECG applications. To obtain ECG signals from the surface of skin, differential mode is used owing to the fact that EPIC has large coupling capacitance(around 250pF) to the body.

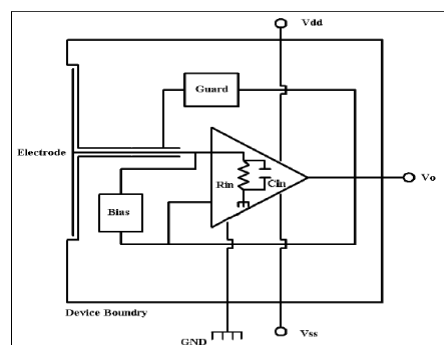


Figure 2. Block Diagram of ECG EPIC Sensor.

EPIC Sensor can be used in non-contact mode for movement and proximity sensing, while in contact mode, it has applications in health and sports monitoring domains. e.g., it can be used for measurement of physiological signals such as ECG(Electrocardiograph), EEG(Electroencephalograph), EMG(Electromyograph), EOG(Electrooculograph) etc. In fact, EPIC can sense ECG even through clothes, making it possible to embed it into sports tops and chest straps[2]-[3].

III. PROPOSED METHODOLOGY

A. COMPONENTS OF SYSTEM

EPIC sensors were surface mounted on a PCB designed for the same. Figure 3 shows the block diagram of the system used for ECG acquisition. The ECG is recorded when the sensors are touched by the left and right thumb of the subject, making it a Lead I configuration. The output from sensors is fed to the first stage of Signal Conditioning Circuit, which comprises the following:

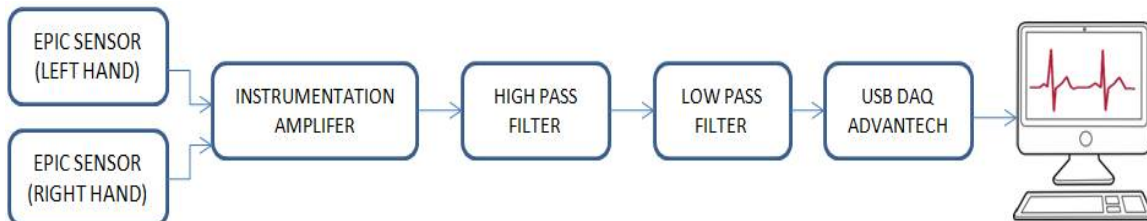


Figure 3. Block Diagram of ECG acquisition system

1. INSTRUMENTATION AMPLIFIER

It acts as a pre-amplifier, which is used to amplify the differential voltage signal taken from the two EPIC sensors and reject unwanted common mode signals with its high CMRR(Common Mode Rejection Ratio) of about 120dB. The external resistance R_g is adjusted such that the gain of the amplifier can be varied. Its high precision, low offset voltage of $50\mu\text{V}$ and low power consumption makes it suitable for battery operated portable systems in biomedical applications.

2. FILTERS

In order to retain ECG signal and discard unwanted components i.e. baseline wandering and offset voltages which can saturate the signal at high gain obtained from instrumentation amplifier, a high pass 2nd order Butterworth filter of cut-off 0.05Hz is employed and cascaded to low pass Butterworth Filter of cut-off 212Hz . Low pass filter removes high frequency noises from the signal. The operational amplifier IC used here was Op07, known to have very low offset voltages and high input impedance which provides high accuracy in non-inverting circuit configuration making it suitable for ECG measurement. The different values of the resistance and capacitance were chosen in accordance with the formula, cut-off frequency $= 1/(2*\pi*R*C)$.

3. GAIN

As magnitude of ECG signal is in the order of millivolt, it requires to be amplified. Figure 4 shows the schematic of preamplifier with low-pass and high-pass filter. The instrumentation amplifier and filter stages provide a total gain of 30.7. The EPIC has inbuilt amplifier which in PS25253 provides a gain of 10 V/V that will enhance signal to noise ratio(SNR). Gain of 10 is further used in wet electrode circuitry for faithful amplification of signal.

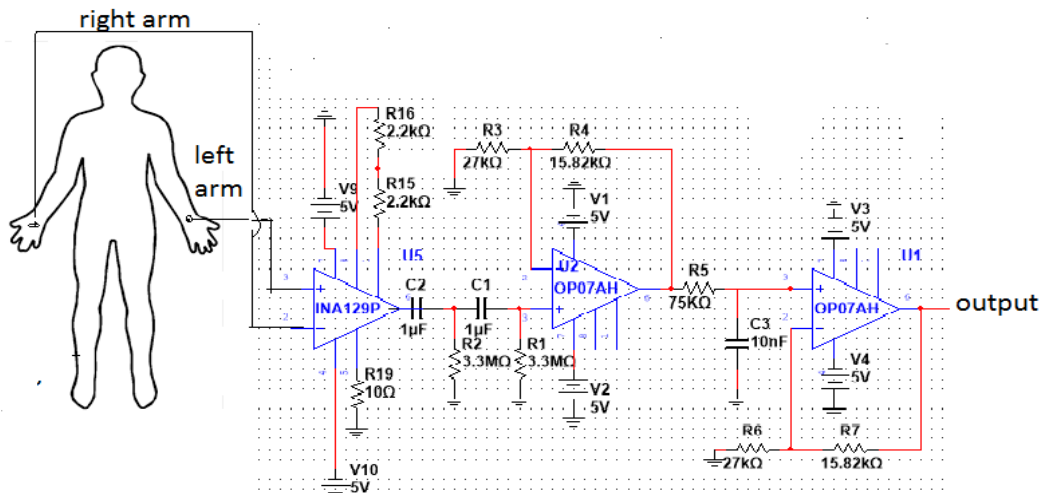


Figure 4. Pre-amplifier and filter circuit diagram implemented for the experimental setup

4. DRIVEN RIGHT LEG (DRL) CIRCUIT

There exists a common mode signal between the body of the subject and the floating ground which needs to be minimized by using driven right leg (DRL) circuit. It is sensed and amplified by the pre-amplifier stage (INA129) which is then inverted and fed back to the Right leg electrode making the DRL signal directly coupled to the patient's skin, as in case of Ag-AgCl conventional wet electrodes. This reduces the power line noise and increases SNR signal to noise ratio substantially. In non-contact ECG acquisition via EPIC sensor, the DRL signal is given to the body through capacitive coupling, using a conductive material/fabric. Since contact-mode of EPIC sensor is employed in our design, DRL is not used while recording through EPIC Sensor. Instead, the subject is allowed to touch simultaneously both the capacitive electrode surface and some metal at the system ground directly with the skin. Grounding is important because it helps in attaining effective shielding of low level circuits to provide a stable reference for making voltage measurements and for rejection of unwanted common mode signals, leading to a high quality ECG signal.

5. POWER REQUIREMENT

In order to provide stable voltages to the circuit, voltage regulator ICs LM7805 and LM7905 are used as positive and negative voltage regulators respectively, providing $\pm 5V$. Since EPIC is an active electrode, it needs a bipolar supply ranging from $\pm 2.4V$ to $\pm 5.5V$, with a supply current typically 2.5mA. To satisfy its power criteria, Zener diode of cut-in voltage 3.3V is used with appropriate resistance in series.

6. DATA ACQUISITION MODULE

The Advantech USB4716 is a data acquisition module with 16 bit resolution and 200KS/s maximum sampling rate. ECG signals are recorded through Advantech USB4716 data acquisition module with 1000 samples per second which satisfies the Nyquist sampling criteria for ECG signal (0.05-212Hz).

B. DATA RECORDING

For recording and comparison, three different ECG data were taken as follows:

- EPIC waveform data using the implemented signal conditioning circuit
- Conventional wet electrode Ag-AgCl ECG waveform data using the same implemented signal conditioning circuit
- ECG signal acquired from standard "AD INSTRUMENTS Octal Bio Amp" using Ag-AgCl.

C. FEATURE EXTRACTION

Feature Extraction helps in extracting diagnostic information from the ECG signal. With R peak having largest magnitude among all waves, its detection is the first step in feature extraction. Method of "Pan and Tompkins" is applied for QRS complex detection and concept of moving average window is applied for P and T wave detection[9-11].

Improvement of the quality of the signal and detection of features of ECG waveform was done on MATLAB (version R2015a). To eliminate baseline wandering and high frequency noise from signal of interest, a digital high pass filter of cut-off 0.3Hz and 70th order low pass FIR filter of cut-off 75Hz are implemented respectively. A digital Butterworth notch filter of band-stop frequency 49-51 Hz is further applied to remove 50Hz power line noise capacitively coupled to the body from the surrounding electrical supply.

QRS Complex Detection

The method of "Pan and Tompkins" was adopted to detect the QRS complex, having maximum variation in the slopes. The algorithm identifies the QRS complexes based upon digital analysis of slope, amplitude, and width of the ECG data and automatically adjusts the thresholds periodically to adapt the changes in QRS morphology and R-R interval.

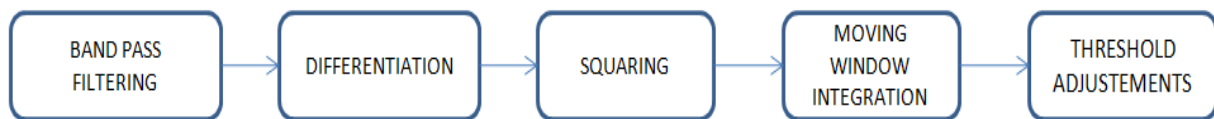


Figure 5. Flowchart of the algorithm used in QRS complex detection

Figure 5 shows the flowchart of the algorithm used to detect QRS Complex. Band pass filter(5Hz-11Hz) attenuates noise in the ECG signal due to myographic noise, power line interference, baseline wander, T wave interference, by matching the spectrum of the average QRS complex. For finding the high slopes of QRS complexes from other ECG waves, derivative procedure is used to suppress the low frequency components of P and T waves, and to provide gain to the high-frequency components arising from the high slopes of the QRS Complex. Squaring operation makes the result positive and emphasizes large differences resulting from QRS complexes; the small differences arising from P and T waves are suppressed. The high frequency and high varying slope components in the signal related to the QRS complex are further enhanced. The integrator finds the area under the squared waveform which passes through MWI (Moving window integration) over a suitable interval, advances one sample interval, and integrates the new predefined interval window. For analysing the amplitude of the MWI output, threshold adjustments are done. These adjustments lower the threshold gradually in signal segments that are deemed to be of poorer quality. This algorithm was applied to the ECG signal obtained from the EPIC sensors and QRS labelling was done.

Figure 6 shows the labelled ECG signal obtained at different steps while implementation of 'Pan and Tompkins method', to detect R peaks. Sampling frequency of ECG signal in the subplots shown below is 1000Hz. Subplots (a),(b),(c) shows the amplitude ranges from -1 to 1 and after squaring, subplots (d), (e), (f) show the amplitude range from 0 to 1. Also, R spikes detection of ECG is required for finding Heart rate.

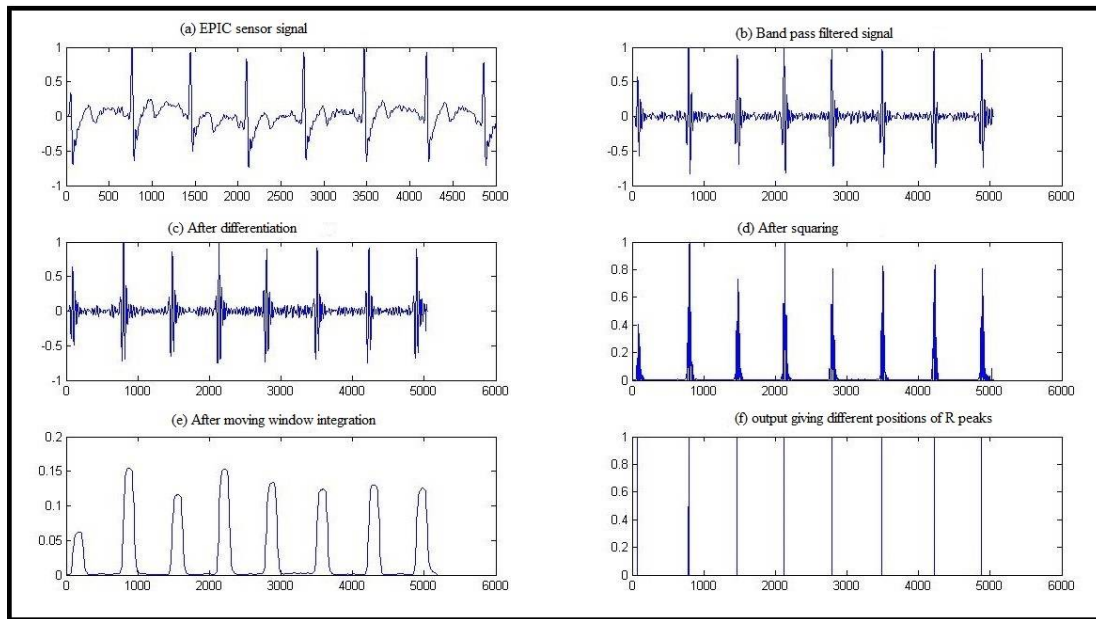


Figure 6. ECG waveform at different stages for detection of QRS complex. x-axis represents the number of samples i.e. 5000 samples taken in 5 seconds. y-axis represents the amplitude of the acquired signal; (a) ECG signal using EPIC; (b) using band pass filter, signal is pre-processed to enhance the contrast between the QRS complex form other events of the signal; (c) differentiated signal; (d) signal is squared to emphasize the large difference from QRS complex and also suppress small difference from P&T waves; (e) signal is averaged using moving window to get rid of noise; (f) position of all R peaks present in the EPIC sensor signal, which is represented by the vertical lines in the graph.

P and T wave detection

Concept of moving average window is employed for the detection of P and T wave of ECG signal.

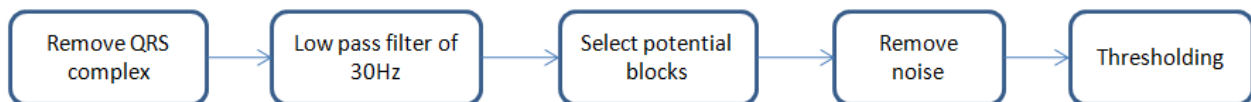


Figure 7. Flowchart of the algorithm used for P and T waves detection

Figure 7 shows the flowchart of the algorithm used to detect P and T waves. The QRS complex is removed from each beat to make the P and T wave dominant by nulling the values before and after the R peaks. This is followed by application of a low-pass filter of cut-off 30 Hz for removal of artifacts and QRS related interferences. The moving averages is used to set the boundaries of the onset and offset of the potential P and T waves, based on a prior knowledge of P and T wave durations. When the two moving averages capture the P wave, it also captures the T wave as T wave duration is higher than the P-wave duration. To explain further, a the second moving average with a larger window size is used as a threshold for the first moving average, which captures the P and T waves simultaneously. When the amplitude of the first moving average (MA1) is greater than the second moving average(MA2), then that segment of the signal is considered as a block of interest. The blocks associated with small width are considered as blocks caused by noise which also need to be eliminated. Thresholding is used to differentiate P block from T block.

Figure 8 shows Q,R,S events and offsets of the P and T-wave of the ECG signal acquired from the EPIC sensors, by applying algorithm of "Pan and Tompkins" for the detection QRS complex and applying moving average filters for the detection of P and T waves..

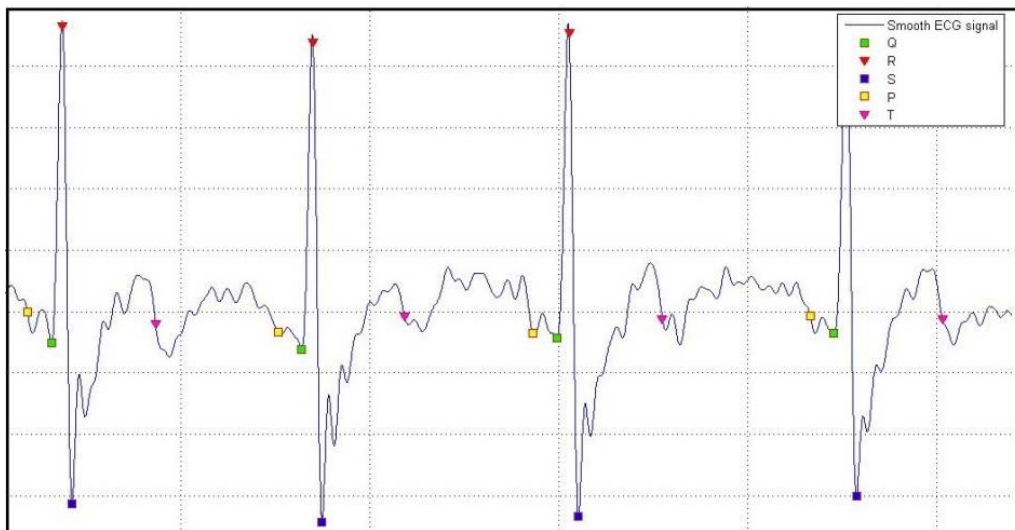


Figure 8. Q,R,S events and offsets of the P and T-wave of the ECG signal acquired for Lead I using EPIC. Location of above mentioned events is done using different symbols of different colours as labelled in the figure itself.

V. RESULTS AND DISCUSSION

The raw signals from EPIC sensor are noisier than those using conventional wet electrodes, owing to higher sensitivity of EPIC towards high frequency noises because of its property to sense even minor electric field perturbations. The filters mentioned in the section III.C of the paper are effective in removing various noises in raw signal. In addition, result from EPIC shows some variation in amplitude from pulse to pulse, owing to the fact that coupling capacitance changes due to body movements and perspiration[5]. Figure 9 shows the raw and filtered ECG signals from the two types of electrode.

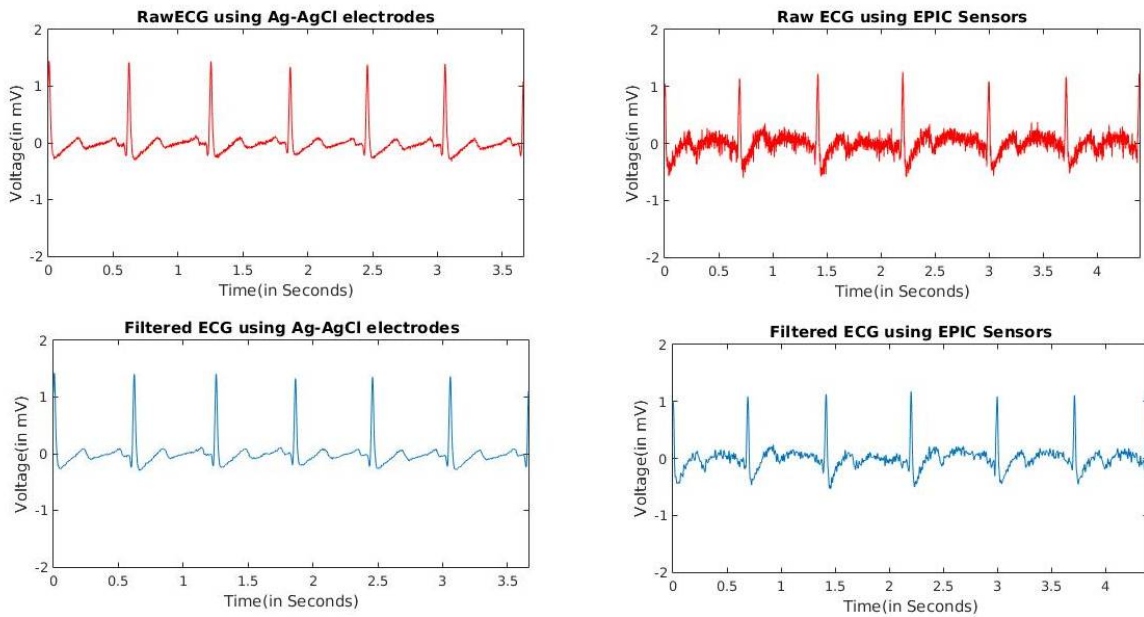


Figure 9. ECG waveform using traditional wet electrodes (left) and using EPIC(right) for Lead I. Traces of top row shows the raw ECG signal while bottom row shows 50Hz filtered ECG signal using MATLAB.

For qualitative comparison, filtered signal obtained using EPIC is further seen against filtered ECG from standard acquisition system using 'AD Instruments Octal Bio Amp' as shown in Figure10. While the signal obtained using EPIC sensors are noisier even after filtering, different digital filtering techniques can be tried in MATLAB to see which gives the best performance. Thus far, FIR and Butterworth filters have been used, IIR and adaptive filtering may prove more effective in noise removal.

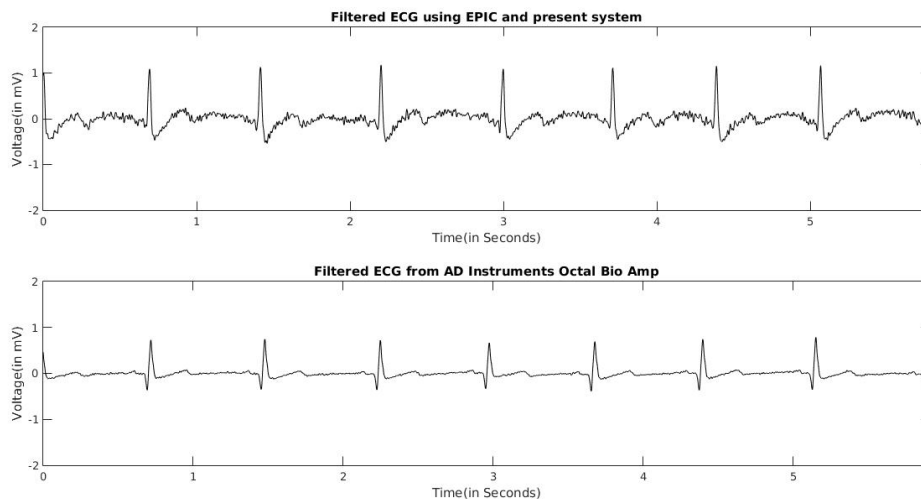


Figure 10. Filtered ECG waveform using EPIC(top) and using AD Instruments (bottom) for Lead I

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Heart beat rate: Algorithm is developed to locate the R peaks and calculate the average rate, obtaining a value of 87 peaks per minute. Heart rate is calculated from the difference of time interval between two consecutive R- points formulated as

$$\text{Heart beat} = 60/(\text{RR interval in seconds})$$

Extraction of basic features like QRS complex and P and T waves helps in finding various parameters of ECG signal as shown in Table 1. Values of the various ECG parameters derived after implementing the algorithms mentioned, were compared with the normal values of those parameters, referred from ECG primer[8]. Following are the normal values of some of the ECG components:

- Narrow QRS complex should occur in time less than 110msec.
- P wave duration should also be less than 110msec.
- PR time interval should lie in between 120-200 msec.
- T wave duration should lie in between 100-250 msec.

ECG parameters	Heart Rate	QRS (in msec)	P duration (in msec)	PR Interval (in msec)	T duration (in msec)
Value	87	60	93	155	141

Table 1. Shows the various parameters of ECG signal obtained using EPIC sensor. Comparing these parameters with the normal values mentioned before, we see that they lie within the normal range, as is expected since the data is taken from a normal healthy subject.

Detection of P and T waves is affected by the quality and abnormalities in ECG recordings; the proposed method can detect P and T waves simultaneously through a unique algorithm despite these challenges[9]. The results from these algorithms can be further validated by using standard Open Source libraries available on physio.net. These values can serve as features for disease classification using Machine learning Techniques.

VI. CONCLUSION

The system design proposed in the paper has a performance comparable with standard ECG acquisition Instrument, in which QRS complex and P and T waves can easily be detected. Though signal quality acquired using EPIC was lower than that acquired using conventional electrodes, it can be further enhanced with more robust digital filtering techniques. It has the potential to be used for long term monitoring with reduced disposable cost, high speed and simplified measurement techniques. Measurements in non-contact mode have very promising prospects as it will very convenient for everyday use and remote monitoring of patients.

In future we would like to modify the present system to utilise non-contact mode of EPIC for 12 lead ECG system, wherein the sensors will be embedded in a stretchable belt/strap tied around the chest for chest leads while around a band for limb leads, providing movement of sensors in two dimensions. This will enable the sensors to be adjusted in accordance with the varying size and shape of different patients. The common mode signal will be coupled to body by feeding it through conductive fabric. Also the performance of EPIC sensors of higher internal gain, 50 will be seen.

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REFERENCES

- [1] RS Khandpur, Handbook of Biomedical Instrumentation, 2nd edition, McGraw-Hill Education, 1992,702p.
- [2] Plessey Semiconductors, "Epic sensor Applications Guidebook". Available: <http://www.advante.ru/components/Plessey.pdf>
- [3] Plessey Semiconductors, "Epic ultra high impedance ECG Sensor Advance Information" PS25253 datasheet. Available: www.plesseysemi.com
- [4] Seema Nayak, M.K.Soni., Dr. Dipali Bansal, "Filtering techniques for ECG signal processing", International Journal of Research in Engineering and Applied sciences, Vol2, Issue2, (ISSN: 2249-3905), pp.671-679,2012.
- [5] Ebrahim Nemati, M. Jamal Deen and Tapas Mondal, "A wireless wearable ECG sensors for long-term applications " IEEE Communications Magazine, Vol50, Issue1, pp.36-43,2012.
- [6] Lukas Smolarik, Dusan Mudroncik, Adriana Libosvarova and Peter Schreiber "Non-Contact ECG signal processing" 6th IEEE international conference on Intelligent System(IS), pp.349-354,2012.
- [7] Bruce B. Winter, John G. Webster, "Driven-Right-Leg Circuit Design", IEEE Transactions on Biomedical Engineering, Vol. BME-30, Issue1, pp.62-66,1983.
- [8] ECG primer, available: <http://www.nursecom.com/ECGprimer.pdf>
- [9] Mohamed Elgendi, Marianna Meo, Derek Abbott "A Proof-of-Concept Study: Simple and Effective Detection of P and T Waves in Arrhythmic ECG Signals" Bioengineering, Vol3, Issue4, 2016.
- [10] Mohamed Ben Messaoud, Besma Khelil, and Abdennaceur Kachouri, "Analysis and Parameter Extraction of P Wave Using Correlation Method", International Arab Journal of Information Technology(IAJIT), Vol.6, Issue1, pp.40-46,2009.
- [11] Shital L. Pingale, "Using Pan Tompkin's Method, ECG Signal Processing and Diagnose Various Diseases In Matlab", Proceedings of IRF International Conference, pp. 22-26, April2014.
- [12] Rangaraj M Rangayyan, Biomedical Signal Analysis ,2nd edition, John Wiley & Sons, New York, NY,2015,720p.
- [13] M. K. Islam, A. N. M. M. Haque, G. Tangim, T. Ahammad, and M. R. H. Khondokar, "Study and Analysis of ECG Signal Using MATLAB & LABVIEW as Effective Tools", International Journal of Computer and Electrical Engineering, Vol. 4, Issue3, June 2012.
- [14] Yong Gyu Lim, Ko Keun Kim, and Kwang Suk Park" ECG Measurement on a Chair Without Conductive Contact " IEEE Transactions on Biomedical Engineering, Vol.53, Issue5, May 2006.
- [15] Advantech "USB4716"datasheet,2015.Available:<http://ieeedataport.org/sites/default/files/analysis/27/IEEE%20Guilines.pdf>