Intelligent ECG Control

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Abstract*— According to World Health Organization, Cardio Vascular diseases are one of the leading causes of deaths worldwide. The enormity of these diseases compels the research capacity to work on this area. A number of devices were introduced in the recent past that can help the doctors diagnose the type of abnormality in heart activity as well as provide immediate assistance to such patients. The main idea of the project is to design and develop a medical facility that is ambulatory and has the ability to detect a few kinds of arrhythmia. The design includes a 3 lead ECG system i.e. 3 strap on electrodes will be used to get the electrical signal of the patient. Electrocardiogram (ECG) is the term for the electrical signal or the heart activity of a person. ECG acquisition and processing circuit consists of amplification and filtering of the signals. The processed ECG will be displayed on laptop's screen. The circuit will be given power by laptop too. The ECG plot can be communicated to a medical expert through cellular phone over the 3G network. To compare the results of the developed system a benchmark device is acquired. The plots from both the devices are observed and heart rate (BPM) recorded. Results show that the ECG plots acquired from the developed system are fairly comparable to that of the benchmark device. Percentage error in the BPM of the developed system is found to be 6.26 on average.

Keywords*— Portable ECG, Arrhythmia, Cardio Vascular diseases, ECG Analysis, Smartphone

I. Introduction

Heart diseases and strokes are the leading causes of deaths across the globe [1]. There is a need to make people aware of the causes and convince them to adopt a healthy lifestyle. A heart monitoring system that could make people aware of the abnormal heart functioning can be useful in this situation.

A variety of devices are available now a day, to monitor the activity of heart, ranging from wearable Holter monitor to Smartphone based heart monitoring application. However electrocardiogram (ECG) is the most advanced and reliable way to observe heart functioning and test for abnormalities. ECG is the technique of analysing the electrical activity of the heart by measuring the potential difference at the surface of body [2]. The typical ECG machine that is in practice in hospitals is very costly and requires an expert to interpret the results from the electrocardiograph. The issue is that the number of medical specialists is very less, especially in under-developed and developing countries, as compared to the number of patients. Therefore, devices that require minimum human intervention are need of the time.

Research has been done on this topic and there are systems proposed for reliable, easy, economical measurement of ECG. Transient abnormal changes that occur in ECG can be detected by the ambulatory ECG monitoring systems efficiently. They consist of microcontroller based signal acquisition and processing circuit along with a display device such as PC. Such systems have the capability to detect QRT complex and ST-segment level change[3]–[6]. However such systems are not intelligent enough to suggest the kind of abnormality found in the heart based on their ECG pattern. Bugtai *et al.* [7] proposed a portable heart monitoring system which can measure the real time heart rate, temperature and ECG of the wearer. The device is useful for sensitive patients who have previous record of or at risk of having a heart attack. But it is a burden for those, who are not prone to experience heart problems under normal conditions, to wear such a product all the time.

To keep the design of ECG device to a very low cost researchers have come up with ideas such as use of scrap material to make the ECG electrodes. An ECG circuit that would require very less power keeping in mind the energy crisis in developing countries is developed. Furthermore according to the strategy director at Vodaphone in February 2009, Terry Kramer, out of 4 million mobile users in the entire world, 2.2 million are in developing countries. Use of cellular phone for the display of ECG signals can be very convenient, handy and economical as most of the population possesses a phone in developing countries according to the above mentioned statistics [8].

We intend to develop a portable, intelligent, energy efficient, user friendly device, 'Intelligent ECG Control'. The device could be operated with minimal technical assistance and after plotting the ECG signal, it would also suggest the type of abnormality prevailing in the heart.

II. Remote Patient Monitoring

Remote Patient Monitoring (RPM) is an up-and-coming field of medical sciences. It is the emerging technology captivating the interest of scientists and re-searchers. This field of medical allows patients to have access to health care outside the clinical setup. Remote patient monitoring is intended to improve the health condition of a patient by making him/her independent and self responsible for health management. Complications that arise in emergency cases can be avoided through RPM [9].

Numerous RPM technologies have come forward. Every technology or idea developed under the umbrella of RPM has a few components in common. These parameters are followed necessarily in their design and architecture. "These are: (i) Sensors on a device that is enabled by wireless communications to measure physiological parameters, (ii) Local data storage at patients' site that interfaces between sensors and other centralized data repository and/or healthcare providers, (iii) Centralized repository to store data sent from

sensors, local data storage, diagnostic applications, and/or healthcare providers, (iv) Diagnostic application software that develops treatment recommendations and intervention alerts based on the analysis of collected data" [10], [11].

Various methods can be deployed in order to incorporate portability or wireless nature in the medical facility. Some instances can be; Wireless sensor networks, use of Smartphone and communication through cellular network etc.

RPM is advantageous because a huge amount of hospital re-admissions can be saved by patient monitoring at their door step. Moreover, this will lead to a better offering of medical services at the higher level. Awareness of patient to his/her illness will improve by involving him in the loop. Furthermore, monitoring the disease will let the patient know about deterioration in time. The mortality rate in our country would decrease if this emerging technology is adopted and welcomed at a large scale. Relationship between doctor and patient can be improved for the stress level of both will be relieved by RPM [12]-[14].

The developed system follows the basic architecture of RPM devices. Sensors used are the ECG limb electrodes and the physiological parameter being monitored is the electrical activity of heart. Smartphone or PC will provide local data storage and can correspond to the expert directly through mobile networks or indirectly through central data base. The software developed shall hold the ability to provide recommendations and assistance to the medical specialist. Artificial Intelligence algorithms and data mining techniques shall be used for letting the patients be aware of their condition.

III. Intelligent ECG Control

An Electrocardiogram is the graphical display of the electrical activity of heart during each heartbeat. This electrical activity is basically the current generated by the heart muscle. Any abnormality in this electrical activity of heart is termed as Arrhythmia. Bradycardia and Tachycardia are types of arrhythmia; bradycardia referring to a heartbeat less than 60 beats per minute (BPM) and tachycardia refers to a heartbeat of greater than 100 BPM.

The authors' idea of an intelligent ECG device comprises of a 3 lead ECG system. After the signal has been acquired, it is fed to the signal processing circuitry which is powered by USB port of laptop. Trace of the heart's electrical activity is displayed on laptop's LCD, the graphical user interface (GUI) for which is developed in MATLAB.

A. ECG Acquisition Module

ECG is the most popular, effective and reliable method to diagnose the Cardio Vascular Diseases. Previous heart attacks and common abnormal heart rhythms can easily be diagnosed by examining the ECG signal and its parameters.

Figure 1 Strap on ECG Electrode [15]

The procedure of ECG includes attaching a number of electrodes to the arms, chest and legs of the patient to detect the electrical impulses from the heart. Then a display of the ECG trace from the impulses is shown by the ECG machine that helps in the accurate diagnosis. Lastly, the electrodes are removed. The procedure takes 5 to 6 minutes.

The waveform of ECG signal is defined on a standard scale. The horizontal axis represents time and the vertical axis represents amplitude. ECGs are usually displayed with 25mm on the horizontal axis representing one second or 40 milliseconds per mm. The vertical axis is 10 mm per mV. Frequency response of ECG signal varies from 0.01 hertz to 150 hertz.

Data acquisition is performed through 3 lead ECG limb electrodes. Two of these electrodes are connected to left and right wrists. The third electrode is connected to right ankle and is a ground electrode. It also provides a path for the displacement current to ground which can otherwise be harmful for the body. The magnitude of ECG signal that is obtained using this process ranges from zero to five millivolts (0-5mV).

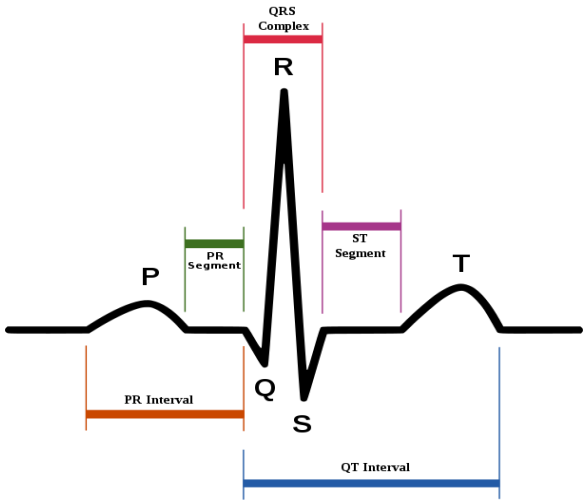

Figure 2 ECG Waveform showing Segments [16]

B. Signal Pre-Processing Module

As told earlier, the signal processing circuitry is being powered by laptop. Since the integrated circuits (ICs) being used for processing require dual supply of 12V DC, 5V DC

supply from laptop need to be converted. NMH0512 dual output converter serves the purpose.

Signal processing is performed in two steps. Partially it is done in the hardware part using instrumentation amplifier, active filters, buffer and voltage controlled oscillator (VCO).

The signal acquired through the electrodes being very weak needed to be amplified before further processing. Instrumentation amplifier is used to achieve good quality amplification. Design includes INA122P which is a high accuracy instrumentation amplifier designed for low-level signal amplification and is well suited for medical instrumentation. An instrumentation amplifier has two stages; Single ended amplification and Differential amplification. In the former, signal from the body is amplified single ended. High input impedance at this stage makes sure that the signal is received at the non-inverting input. In the latter stage signal is amplified differentially to remove the common noise. Common mode rejection ratio (CMRR) is maintained at this stage.

After amplification the signal is filtered from unwanted interferences from other signals. For this purpose a band pass active filter is used designed using NE5532P op-amp IC. In the next step, buffer is incorporated for impedance matching and its output is sent to the modulation circuitry.

We are transferring the ECG signal to the laptop's soundcard through audio port that works in the audible frequency range i.e., 20 Hz - 20 kHz. Since the signal has a very low frequency range (0.05 Hz – 106 Hz), therefore, it is modulated to a higher carrier frequency to make it compatible with the soundcard. This is performed using CD4046B VCO IC. The carrier frequency for this purpose is selected to be 3.3 kHz and the circuit is working perfectly.

C. Interfacing Module

The modulated signal is sent to the laptop through its audio port using a 1 meter long 3.5mm audio cable.

D. Signal Post-Processing Module

The remaining portion of signal processing is completed in software. The software used for this purpose is MATLAB®. MATLAB® is chosen because of its high processing power, wide range of toolboxes and the ability to cope with multiple programming languages. The signal is further purified here and then various features of the ECG are extracted.

E. Signal Analysis Module

ECG is plotted on a standard graph paper. This paper is reproduced in MATLAB for the measurement of the acquired signal. The scale of the paper is as: (i) One big square (5mm) on the horizontal axis represents 200 milliseconds and (ii) One big square (5mm) on the vertical axis represents 0.5 millivolts.

The analysis is based on the parameters extracted from the patient's ECG plot. Programming is done to inculcate the ability of suggesting the type of abnormality in the equipment. The device is able to detect the following types of arrhythmia; (i) Tachycardia, (ii) Bradycardia. In this way the device can give recommendations to doctor about the type of anomaly and can help reduce their workload.

F. Data Storage Module

Parameters obtained from the ECG plot can be stored in an electronic database in order to keep record of the patient. Data of one or multiple patients can be retrieved at any time from any location through internet. A separate profile is created for each patient and personal information of patient along with the diagnostic results can be saved in it. This profile can then be referred at the time of future consultancy. In this way doctor can keep track of patient's history.

G. Data Communication Module

The ECG plot and results can be sent to specialist for expert opinion using wireless communication. This is helpful in case the abnormality found in the heart could not be interpreted or it is of a crucial level.

Complete block diagram of the project is shown in Fig. 3.

Figure 3 Block Diagram of the Project

IV. Results And Findings

The ECG plots acquired from the developed device are compared with the response of commercially used ECG machine in hospitals shown in Fig. 4. This machine detects as well as amplifies the electrical impulses during each heart cycle and plots them on a standard graph paper. The patient is monitored for about five minutes.

Figure 4 Commercially used ECG Device as Benchmark [17]

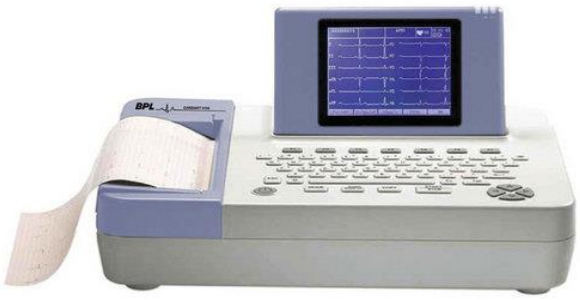

Figure 5 ECG Signal from Benchmark Hardware [18]

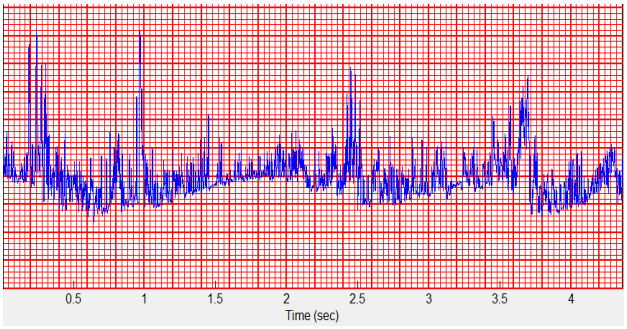

Figure 6 Results from Author's Device

For comparison purposes, ECG signal using the benchmark device has its output response shown in Fig. 5. The authors' 3 lead ECG signals observed on a laptop screen are shown in Fig. 6. Comparing the two results it can clearly be seen that ECG signals from the designed hardware are positively comparable with the state of the art.

For verification, the developed system has been tested on 20 subjects belonging to the age group of 15 to 40. Some of the results are shown in the table 1.

TABLE I
COMPARISON OF RESULTS

Serial No.	BPM measured by Authors' Device	BPM measured by Benchmark Hardware	Age (yrs)	%age Error
1	65	62	33	4.84
2	77	82	22	6.09
3	66	70	34	5.71
4	86	78	18	10.25
5	86	90	20	4.44

V. Future Work

This work has been done by students as their final year project in limited time. It can be further enhanced by adding more features which could improve its performance.

Currently the device first records the ECG signal and then plot it. Real time health parameter is very important [19]. According to American Heart association [20], a survival rate of 48%-75% can be brought to a patient experiencing ventricular fibrillation by the treatment within the first 12 minutes of cardiac arrest. The survival rate drops to 2%-4% after this time has passed. For this, the device can be improved to plot ECG in real time.

A Smartphone application can be developed to perform the signal processing and analysis. This is possible by converting the MATLAB's C language code into Java. This would kick off the laptop/PC from the system loop and make the device handier. As Smart phones are very common now days, the smart phone app would increase the comfort level of users.

A further development that can be done in the current system is to improve this system so as to obtain the ECG of the adult and CTG of the fetus by the same device. As the hardware circuit for both purposes are quite similar with the difference of only a few sensors, so this can be easily done. With this advancement, one can be able to examine the heart of fetus and adult with the same device by only switching between the modules.

VI. Conclusions

The aimed design has been successfully developed and implemented with an accuracy of 93.74%. The results obtained are fairly comparable with state of the art ECG machines. Further accuracy can be achieved by employing adaptive filtering techniques in software.

Developing countries like Pakistan are facing an enormous power crisis. The developed system has its power supplied by the laptop through USB port. This allows the device to be used in far flung areas where the facility of electricity is unavailable and during load shedding hours. Keeping in view the low doctor to patient ratio in developing and under-developed countries, 'Intelligent ECG Control' can help reduce the doctors' workload. The device is able to give recommendation to medical expert about the type of heart abnormality, hence reducing the average time required for the diagnosis. In this way, large number of patients can be treated in less time and health sector of these countries can advance.

Our device does not require an expert to operate, thus making it able to provide immediate assistance to cardiac patients anywhere. By this, deaths due to cardiac failures can be reduced as the patient aware of his/her condition would see the doctor and get treatment in time.

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