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Design and implementation of portable electrocardiogram recorder with field programmable gate arrays and IoT interface

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ABSTRACT

The electrical activities of the heart are used to monitor cardiovascular diseases. It can be measured using electrocardiogram (ECG), a simple, painless test that can be recorded graphically. The physician, to predict the patient's heart conditions and recommend suitable treatments, uses electrodes placed on the patient's skin surface, to record these signals. The P, Q, R, S, T waves in the ECG signal can be used to determine the normality and abnormality of the heart's condition. The time interval differs for each cardiovascular condition of the heart. In this work, the ECG signal is acquired real-time using an intelligent sensor module, and the recorded value is processed to find the peak values. The data is sent to the web server using internet of things technology at a minimal time, where the physician can view it and proper decision can be taken. The real-time ECG data acquisition is also made using the field programmable gate array kit as it is a low cost, high-speed device and the output is viewed in the computer. The developed model is validated through MATLAB software and implemented for real-time applications.

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1. INTRODUCTION

The cardiovascular diseases, such as stroke, arrhythmia and coronary illness, becomes fatal if they are not observed on time. They are helpful in taking necessary precautions as a form of life saving measures [1]. Electrocardiogram plays vital role before and after birth as they can be used to identify congenital disease. The electrocardiogram is used to plot the electrical signals of the heart, they are useful in identifying the ectopic beats from the normal beats. The chronic heart diseases need a long-time monitoring. As the technology is growing every day it allows people not to be confined in their hospital beds, but allow them freedom to monitor their health from their home.

The remote monitoring electrocardiogram (ECG) allows the physician to observe the patient on a timely basis and can help them by sending alert messages in case of emergency [2]. This comes as a timely help in saving a patient. The ECG signal comprises of P, Q, R, S, T signals as shown in Figure 1. Each of these have a significant role in detecting the patient's condition. Any deviation in them indicates the abnormality of heart which needs immediate diagnosis [3]. A simple three lead ECG uses three electrodes to record ECG signal by placing one electrode on the left leg (LL) and one on each arm (right arm (RA), left arm (LA)). These three points are known as Einthoven's triangle [4].

The ECG electrodes are connected with the ECG recorder. This ECG recorder is used to measure the potential difference between each pair of electrodes in millivolts (mV). The formation of the Einthoven's triangle is shown in Figure 2. After these signals are received from the sensors, they are filtered of the noises using a control unit, and they are transferred to cloud storage through Wi-Fi modules or Bluetooth devices and can be viewed in mobile or web platforms [5].

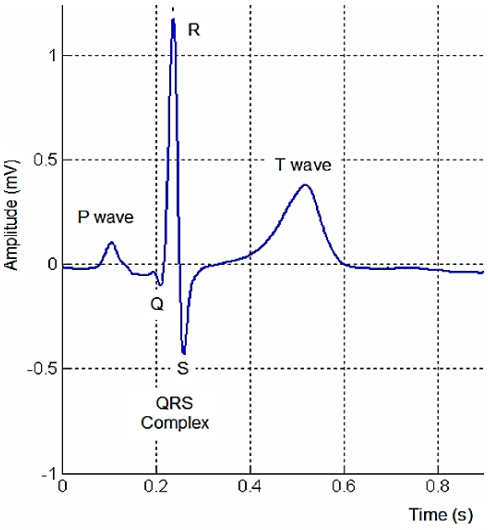

Figure 1. Peaks in ECG [3]

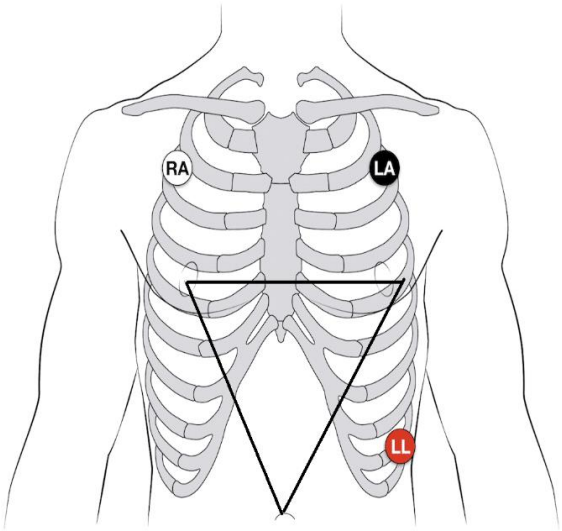

Figure 2. The three ECG electrode placement in Einthoven's triangle [4]

2. LITERATURE REVIEW

The modern broadcast technology for tele homecare provides innovative opportunities for observing necessary parameters using sensors [6], [7]. It gives the patient the right to be free and still be under continuous monitoring, thereby increasing patient care [8]. The irregularities of the heart rhythm can be determined by evaluating the R peak value in the Q wave R wave S wave (QRS) complex. Different filters are employed to remove noise and Hilbert transform and adaptive threshold is used for peak and R peak detection respectively [9]. The field programmable gate arrays (FPGA) based noise detection and removal of baseline noise using filters were tested using the signals from the MIT BIH database [10]. It should be noted that FPGA is very beneficial when compared to digital signal processing (DSP) processors as they are of low cost and high speeded reprogrammable devices. The real time processing of ECG signals is done using FPGA, and Hermite functions are used to process the acquired ECG signals and heart beat classification [11], [12]. A system that could be beneficial and economical for patients to measure ECG using an Arduino Nano board, which acts as a sampler and analog to digital converter (ADC) [13]. Here, Java API and windowing algorithm is used to analyze P wave Q wave R wave S wave T wave (PQRST) intervals. The ECG signals obtained from physio net database is filtered using Butterworth filter and denoised using notch filter, after which feature extraction and heart beat detection is done in LabVIEW software [14]. A portable system where the ECG data is obtained with 12 lead data acquisition systems for home health care to benefit older people is proposed in [15].

A system that uses LabVIEW software to view the ECG signal that are sensed using various wireless sensors nodes, is connected to the nursing room node where they can be visualized and monitored is proposed [16]–[18]. A wireless sensor network is proposed to monitor the patient's illness and connect the patient with ECG and BP sensors. An Arduino board is used to transmit the acquired signal through Bluetooth, after which, they are processed to determine whether the obtained ECG signals are normal or abnormal [19]–[22]. A system that transfers ECG data from one place to another through internet of things (IoT) technology is developed. They used the cloud storage to store the obtained data. The Bluemix, an IBM cloud, is used for this purpose and has a lightweight protocol developed for machine-to-machine communication [23]. An ECG Holter system to monitor the patients with arrhythmia using an android mobile application is implemented. It consists of 3 electrode sensors, a Bluetooth module that connects the system to a smartphone [24]. A portable device that uses Arduino and an ECG recording machine that can be used to learn the ECG waveform and display the wave is introduced [25].

3. METHOD

Generally, the digital signal processing (DSP)-based processors are used for processing any signal as they are specially designed for this purpose; the DSP processors tend to be high-speed processors with better accuracy. But they are not convenient for the programmers and are not easy as the field programmable gate array (FPGA) or other processors that can be written in Verilog and C language. These processors are costly too. The FPGA processors are also faster and have parallel processing with a speed of 40 MHz. They have an option to be custom designed and have flexible architecture. The other processors, such as advanced RISC machine (ARM), Arduino can be used for making special applications and uses sequential processing with a speed of 20 MHz. The ECG data can be measured and used practically by using an Arduino UNO. Though digital data could be transmitted, plotting a continuous signal may be a complex one. So, the diagnosis of the patients can be made using the R-R peak interval, P wave, P-R wave and QRS wave values, which are measured in milliseconds. They can help us in demarcating the normal and abnormal ECG recording. The recording of the ECG wave is done with the FPGA device using a data acquisition module with an amplifier and signal conditioning circuit designed in Verilog language. Table 1 shows the ECG wave parameters.

The ECG signal plays an important role in detecting Cardiac problems. The continuous monitoring of the elderly patient requires special and simple device as the normal hospital ECG machine cannot be used for their diagnosis at home. So, an easy and economically cheap ECG recorder machine is proposed, where the recorded ECG can be transmitted using a Wi-Fi module, ESP8266. This technique enables the physician to check the peak values thus they can examine the patient's condition. This can be done by connecting the ECG data acquisition system with the Arduino where the required parameters are measured so that they can be transmitted through an IoT device this system takes minimum of 5-6 seconds for every update. The parameters such as P wave, QRS interval, RR interval can be used to do the diagnosis of the patient. The analysis of the acquired signal can be done by using the measured signal in the MATLAB environment. The bock diagram for the ECG data acquisition system using Arduino is shown in the Figure 3.

The ECG data acquisition can also be done using FPGA kit where the amplification and signal conditioning stage is done using the Verilog coding and AD8232 is used for ECG data acquisition. Figure 4 shows the data acquisition done using FPGA Spartan 3. This shows the measurement of ECG data using a sensor and audio jack connected to an AD8232 heart rate monitor. Thus, acquired signal is fed to the FPGA kit where the amplifier and signal conditioning circuit is designed. The setup is tested with people of age group 20-30.

Table 1. ECG wave parameters

ECG parameter	Typical wave duration (seconds)
P-R interval	0.12 to 0.20
R-R interval	0.6-1.2
QRS interval	0.09
P wave	0.11

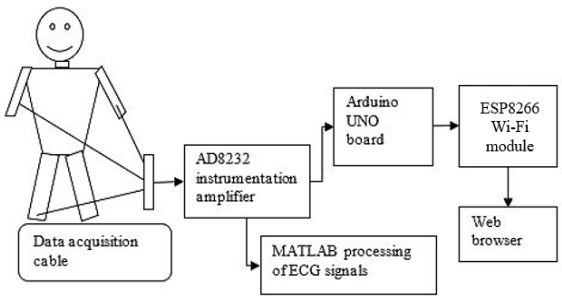

Figure 3. Block diagram of the ECG internet of things

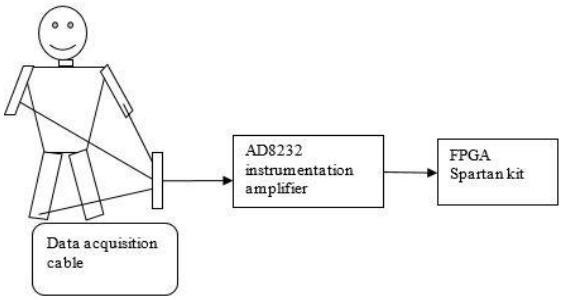

Figure 4. Data acquisition using FPGA

The Figure 5 shows the complete setup of the ECG recording device with the Wi-Fi module. This setup consists of the ECG data acquisition setup system which consists of an electrode that is connected to the ECG AD8232 instrumentation amplifier through a 3.5 mm audio jack. This setup is then connected to an Arduino board where the signals are processed at 9600 baud rate and the output is sent to two modules, one is the Wi-Fi module and another is the UART-USB connector module. The AD8232 amplifier receives the analog data from the 3-lead ECG jack with electrodes. These electrodes are disposable after using once or

twice. They can simply receive the data from the skin contact. These received analog data are sent to the amplifier stage, where the basic noises are removed by default. This setup is connected with the Arduino board, where the obtained ECG values can be plotted and processed in the Arduino GUI using serial plotter or serial monitor.

The values that are processed such as the peak-peak value, and QRS value are send through the Wi-Fi module to the web IoT server (iot.iotweb.in). These data are also processed in the MATLAB for their peak, heartbeat, QRS rate, and can view the ECG signal. This can be done using UART-USB cable that can connect the Arduino to the computer. The processing is done with the help of MATLAB 2014a software tool. The FPGA setup is used for implementing the pre amplification stage after acquiring the ECG signal which is shown Figure 6. This setup consists of the data acquisition and the amplification with signal conditioning stage. This amplification stage is implemented by Verilog coding which is a hardware descriptive language that does the amplification process.

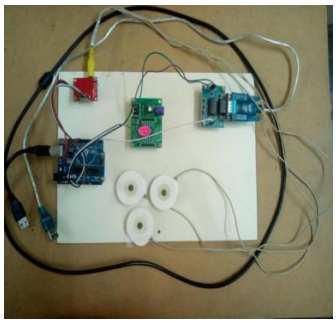

Figure 5. Complete ECG setup

Figure 6. Hardware setup using FPGA

4. RESULTS AND DISCUSSION

The output from the data acquisition setup, which consists of the electrodes, 3.5 mm audio jack and the AD8232 ECG heart rate monitor, is given to the Arduino microcontroller through the analog input pin A0 and the LO+ and LO- are connected to the pins 10 and 11. The Arduino is connected to the Wi-Fi module which transfers the data in the IoT server which can be displayed in the webpage. The output from the Arduino board that transfers the data to the IoT server each time when peak values are obtained and when other required parameters are obtained.

Now once the values are sent, the computer may read the values through the UART-USB cable through the serial COM port. Now the values are read by the MATLAB through some codes and are used to detect the R peak interval, R peaks bit rate, heart rate of the person. The real time signal viewed in the MATLAB is shown in the Figure 7. The MATLAB reads the real time data through the serial port and stores the value in a text file which can be processed whenever needed. The final output of the signal, after the specified interval, produces the following output where the complete obtained wave can be seen as shown in the Figure 8. This shows the ECG signal obtained from the Arduino.

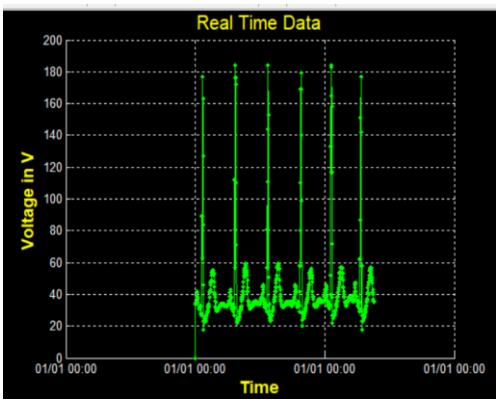

Figure 7. Real-time window to monitor ECG

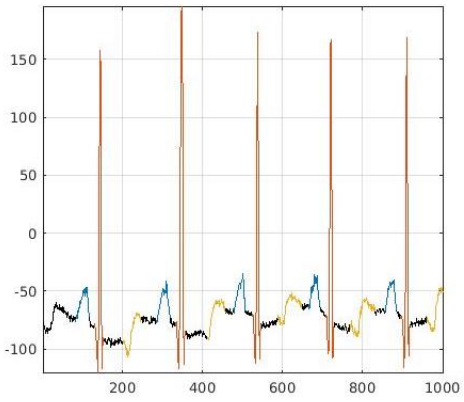

Figure 8. Signal output with interval

The filtered output obtained at the end and has various peaks such as R, S, T with filtered ECG output indicated in the plot is shown in Figure 9. The data are then transferred to an IoT cloud platform so that they can be viewed online. The IoT data consists of RR value, P value, QRS value with time when they are measured. The output from ECG is shown in Figure 10 is the filtered output that is obtained using the FPGA kit connected to an ECG application viewer.

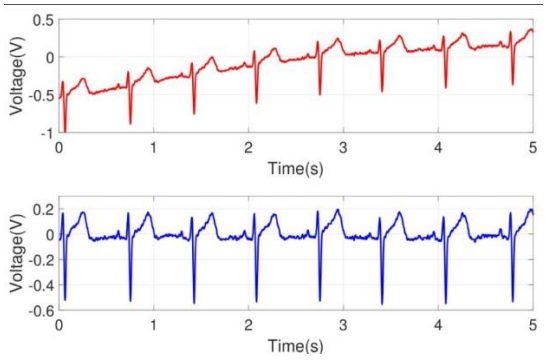

Figure 9. Processed output with peaks detected

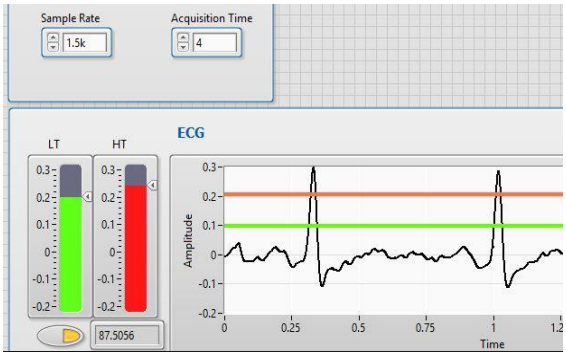

Figure 10. Final ECG output received

5. CONCLUSION

The cardiovascular diseases have been increased in its rate during the last years. ECG is one of the techniques that can be used to detect the cardio vascular disease and during operations for any serious injury. To monitor the elderly patients the mobility of an ECG recorder can play a vital role. Along with the IoT development in the upcoming years it is possible to transfer data from one end to another without human intervention. The portable recorder designed with the Arduino device which can find the peaks in the obtained ECG signal and can help in diagnosis of the patient for the physician. This data can be viewed by them from anywhere and can inform them or may it easy to treat the patient's when their condition becomes critical.

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