Design and implementation of low cost ECG monitoring system for the patient using smartphone

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Design and Implementation of Low Cost ECG Monitoring System for the Patient Using Smartphone

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***Abstract*—Electrocardiographic (ECG) equipment plays a vital role for diagnosis of cardiac disease. However, the cost of this equipment is huge and the operation is too much complex which cannot offer better services to a large population in developing countries like Bangladesh. In this paper, we have designed and implemented a low cost portable single channel ECG monitoring system using smartphone having android operating system and Arduino. This manuscript also demonstrates the use of Android smartphone for processing and visualizing ECG signal. Our designed system is battery powered and it gives wireless feature. This system can also be used with desktop computer or laptop having either Windows, Linux or Mac OS. For this purpose a software is developed. An Android application is developed using Processing IDE, which requires Android version 2.3 and API level of 10. This application does not need USB host API. For this reason, around 98% Android smartphone in the market can be used for this system.**

Keywords—Electrocardiogram (ECG); Arduino; Power Line Interference; Smartphone

I. Introduction

Electrocardiogram (ECG) is the recording of the electrical activity of heart. ECG signal is a bipolar low-frequency weak signal and the normal rage of the signal is 0.05-100Hz [1]. Its amplitude ranges from 10µV to 5mV, whose typical value is 1mV. ECG signal can help to diagnose several heart related diseases.

Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels. CVD remains the leading cause of death around the world. About 29.6% of all deaths worldwide (15 616.1 million deaths) were caused by CVD in 2010 [2]. The mortality for men and women for cerebrovascular disease (stroke) and coronary heart disease (CHD) are shown in Figure 1 [3]. By 2020, non-communicable diseases including CVD are awaited to account for seven out of every 10 deaths in the developing countries [4]. Major risk factors of CHD includes unhealthy diet, above-optimal levels of total cholesterol and blood pressure, and cigarette smoking [5]. In Bangladesh, about 20% of adult and 65% of elderly people suffer from hypertension [6]. In 2010, the International Diabetes Federation estimated that 6.1% and 7.1% people living in Bangladesh suffer from Diabetes mellitus (DM) and impaired glucose tolerance (IGT). In diabetes patients, myocardial ischemia is often asymptomatic, which increases the mortality [7].

Our research study aims to develop a low cost ECG monitoring system, which is real-time, affordable, portable and user-friendly. In this research a prototype ECG monitoring system is developed which is low cost, portable, battery powered and it includes wireless facility for safety concern and reducing noise interference. It gives wireless connectivity up to 9 meter. Our designed system visualizes the ECG signal and heart rate, it doesn't detect abnormal ECG signal. In the system, we developed a software for desktop computer and an android application to visualize the ECG signal. This system consists three electrodes, by which ECG can be taken from either limb leads (Lead I, II and II), and augmented limb leads (aVR, aVL, and aVF). The equipment used in this system consumes low power for this it can function for a long time. In Bangladesh, per capita electricity generation is only 321 KWH and this system can be used during load shedding and on those remote areas where electricity have not reached [8].

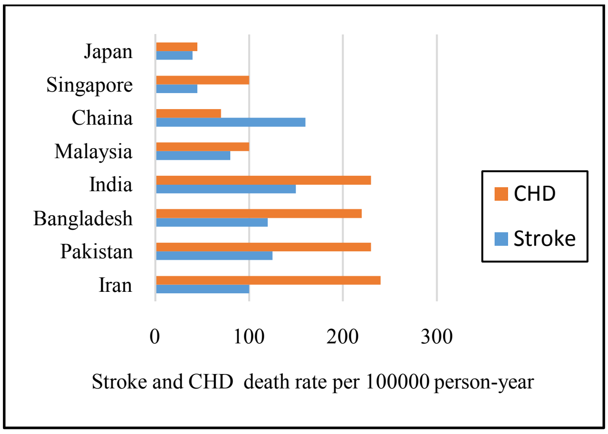


Fig. 1. Death rates per 100000 for stroke and CHD across countries of different regions of Asia in 2002.

II. System Architechure

Modern smartphones have more processing power and other features like Bluetooth (IEEE 802.15.1), Wi-Fi (IEEE 802.11) and 3G. Among smartphones, Android operating system is becoming more popular nowadays and currently it dominates about 81% of world smartphone market [9]. This makes it an attractive platform to implement low cost ECG monitoring system. Arduino Uno is a low power and highly efficient microcontroller board based on the ATmega328. It has built in ADC and USART communication feature. In this system, for analog to digital conversion and serial transmission of the ECG signal Arduino Uno is used.

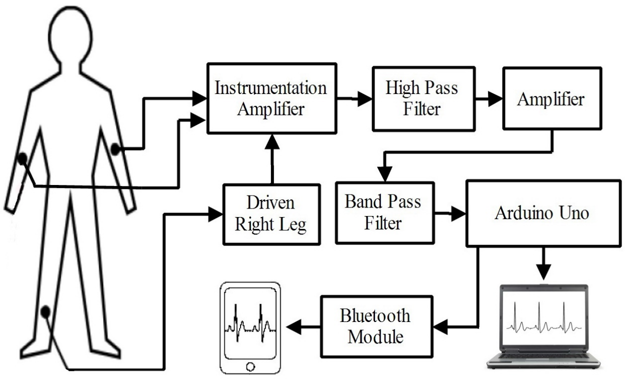


Fig. 2. System Architecture of the ECG monitoring system.

III. Methodology

The proposed system consists of four units: a sensor unit consisting of ECG Electrodes and patient cable, a signal conditioning unit consisting of amplifier, Filter, leg driver, a power supply unit and a Microcontroller unit consisting a Bluetooth module.

A. ECG Acquisition

For sensing ECG signal, skin-surface transducers called Ag/Ag-Cl electrodes are used. A commercially available electrode named Bio Protech T716 is used which is shown in figure 4. These signals are transferred to the amplifier input by using the patient cable.

B. Signal Conditioning

The quality of the recorded ECG signal is affected by the skin-electrode-amplifier interface, electrode motion artifact, electrical interference, semiconductor noise generated in the amplifier, and input signal level variation. In this system we use AD620 because it's a low cost, high accuracy instrumentation amplifier, having CMRR greater than 100dB to nearly 1 kHz [10]. Total gain required is 703.8, which has been achieved by two stage amplification. Two stage amplification is done to avoid the risk of amplifier saturation, which generally occurs due to amplification of electrode offset voltages. To set the gain of AD620, a single external gain resistor R_g is used and the gain expression is given in Eq. (1) [10].

$$Gain = 1 + \frac{49.4k}{R_g} \tag{1}$$

The gain was selected to be 13.7 by setting R_g to 3.9kΩ for first stage amplifier. Second stage amplification is done by CA3130. It was used as non-inverting amplifier and voltage gain of 51 is achieved. For filtering a high pass filter of 0.03 Hz cut off frequency is used for removing high frequency noises. A band pass filter is implemented using a high pass filter of 0.03 Hz and low pass filter of 159 Hz cut off frequency in cascade. All those filters are passive first order filter and cut off frequencies are calculated by the Eq. (2) [11].

$$f_c = \frac{1}{(2\times\pi\times R\times C)} \tag{2}$$

The ECG signal is superimposed by a large electrode DC offset potential and a large common mode voltage. The sources of a common mode voltage are generally 50 Hz or 60 Hz line frequency noise and electrode DC offset potential. A driven right leg circuit is used to eliminate the common mode signals. It inverts and amplifies the average common mode signal back into the patient's right leg, which cancels line frequency noise and also improves the common mode rejection ratio [12]. The internal ADC of Arduino Uno works between 0V to +5V [13]. For this, a virtual ground of 3.3V is used as reference of AD620. It makes the bipolar ECG signal to Unipolar. Figure 3 shows the signal conditioning circuit for this system.

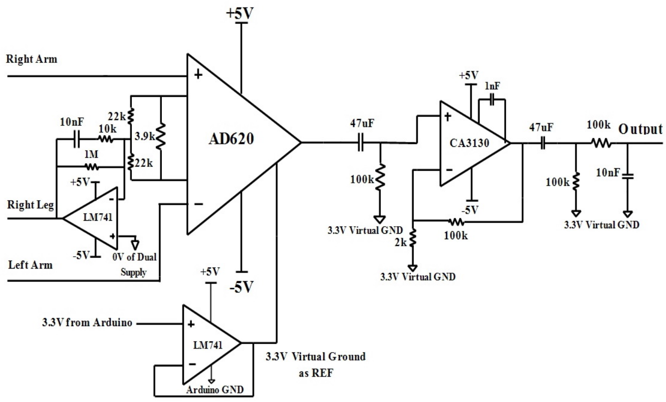
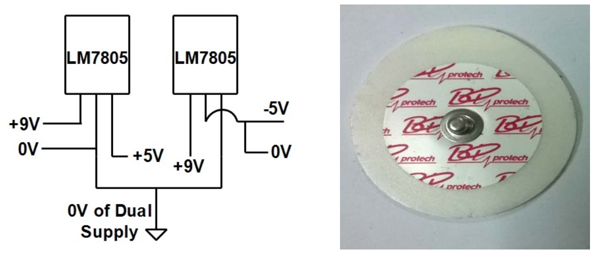


Fig. 3. Signal conditioning circuit using OP-AMP.

C. Power supply

In this system two 9V disposable Lithium battery is used for making it portable. For safety and short circuit protection, a voltage regulator LM7805 is used. In this system all equipment gets power from battery. It is done to avoid power line interference (50Hz) and other noise interference.



(a) (b)

Fig. 4. (a) Designed power supply for the system. (b) Bio Protech T716 ECG electrode

D. ADC and Serial Transmission using Ardunio

Arduino UNO board contains a 6 channel 10-bit analog to digital converter. It returns a linear value from 0 to 1023 corresponding to 0V and +5V respectively [13]. For serial transmission baud rate is taken as 9600 bps and sampling rate of 320 samples per second is used. Arduino Uno has a built in USART communication feature which allow USART transmission and reception via digital pins 1 and 0 [13]. For serial communication pin 1 and pin 0 of Aduino Uno needs to connect with Bluetooth modules Rx and Tx and figure 5 shows the connection. A Bluetooth module HC-06 does signal transmission between Arduino UNO and Android phone. Arduino Uno can also communicate with laptop via USB cable.

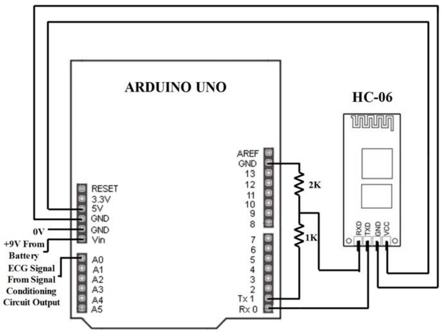


Fig. 5. Connection for Arduino UNO and Bluetooth module HC-06.

IV. Software Implementation

There are two main parts of the software structure and they are device layer and application layer. The device layer is used to drive hardware and the application layer is for user to visualize the ECG signal. For programming the microcontroller, integrated development environment provided by the Arduino platform is used. An Android application and a software for laptop is developed by processing which is an open source programming language and integrated development environment IDE. We used Processing IDE of version 2.21. For receiving serial data from Bluetooth module, BtSerial and Ketai library was used [14-16]. For developing the software used in laptop serial library of processing was used to receive the data from Arduino Uno. ECG signal is visualized using line() function [14-15]. For storing the ECG signal println() function was used, which creates a txt file and save the values received from Arduino ADC.

V. Experimental Measurements And Results

Android phone used for visualizing the ECG signal has Qualcomm MSM8212 cheapest and 1GB ram running on Android 4.3 operating system. In figure 6 ECG signal is displayed in Android phone.

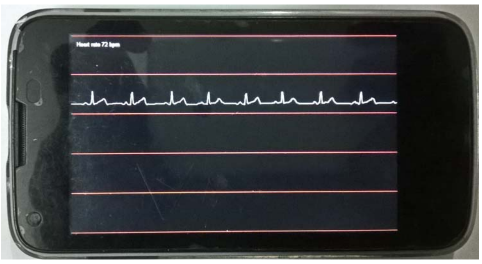


Fig. 6. ECG signal in Android smartphone.

We have implemented the circuit in veroboard. This system can work together with laptop and smartphone or individually by using only smartphone or laptop. In figure 7 both laptop and smartphone is used. The Laptop has Intel Celeron B820 (1.7 GHz) processor and 2GB ram running on windows 8.1 OS. In laptop data of the ECG signal is received by USB cable which is connected to Arduino Uno. In Android phone it is received by Bluetooth module. We have saved the data of ECG signal in text file using the software. For analysis, MATLAB R2014a is used. ECG data stored by the software is imported in MATLAB. The ECG signal was taken from a boy of 23 years old in LEAD I. Figure 8 shows the ECG signal without filtering. It contains noise and power line interference (50 Hz).

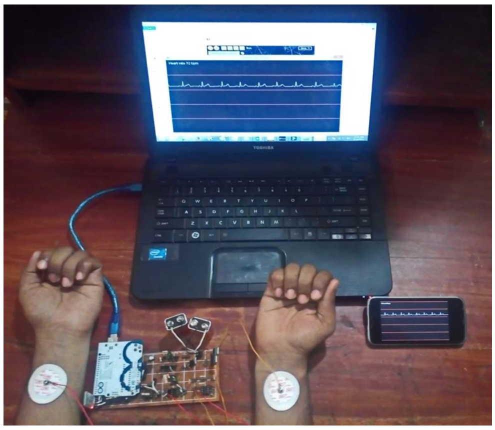


Fig. 7. Experimental measurements performed by us.

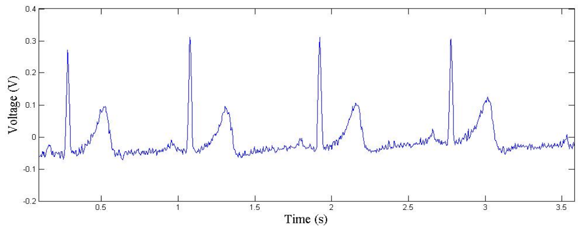


Fig. 8. ECG signal without filtering.

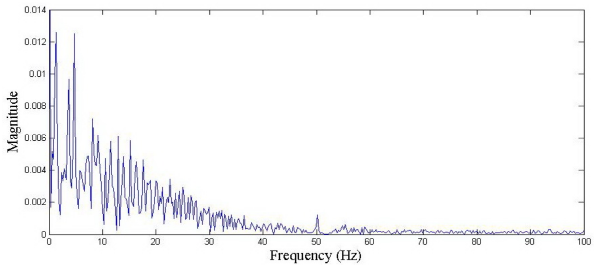


Fig. 9. Frequency spectrum of the ECG signal.

Figure 9 shows the frequency spectrum of the ECG signal without any implementation of digital filter in MATLAB. In this figure, magnitude for 50Hz is 0.001233 and that is for common-mode voltage produced by the ac mains of 50 Hz frequency with line voltage 220V. Due to this ECG signal in figure 8 is contaminated with power line interference (50Hz). Though, in this system signal conditioning and signal transmitting circuit is isolated from ac mains there exist a small amount of power line interference. This is because of the capacitance between power lines in the wall, floor and nearby equipment couples current into the patient, wires and system equipment.

For filtering first, a 4th order butterworth band pass filter was implemented with a lower and higher cutoff frequency of .033Hz and 120Hz. After that a 4th order elliptic band stop filter of 50Hz was implemented having Rp=5, and Rs=30. Filtered ECG signal is shown in figure 10 and figure 11 shows its corresponding power spectral density.

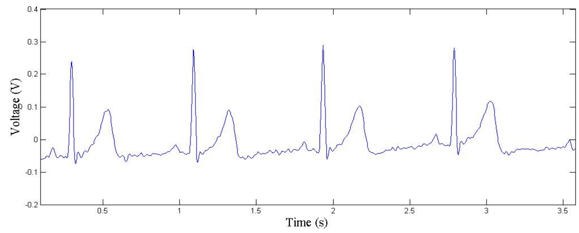


Fig. 10. Filtered ECG signal.

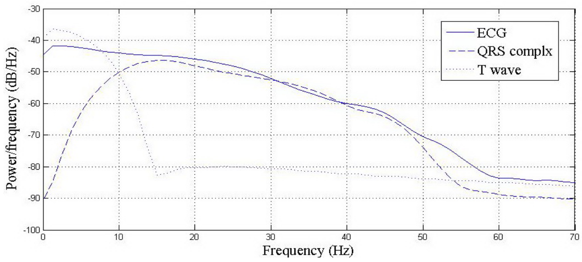


Fig. 11. Power spectral density of the ECG signal, QRS complex and T wave.

TABLE I. shows different ECG parameters measured by MATLAB and all those intervals are found in normal range.

TABLE I. MEASURED ECG PARAMETERS

Parameter	Normal Range	Measured	Unit
Heart Rate	60-100	72	Beats per minute
RR Interval	0.6-1.0	0.831	S
PR Interval	0.12-0.20	0.127	S
QRS Interval	0.06-0.1	0.085	S
QT Interval	0.36-0.44	0.365	S

VI. COST ANALYSIS

TABLE II. COST OF THE EQUIPMENTS

Component Name	Quantity	Unit Price (USD)	Total Cost (USD)
Arduino UNO	1	9	9
HC-06	1	6	6
AD 620	1	6	6
Resistor	12	0.01	0.12
Capacitor	2	0.02	0.04
LM 7805	2	0.15	0.3
CA3130	1	0.25	0.25
LM 741	1	0.15	0.15
ECG Electrodes	3	0.09	0.27
9V Battery	2	0.5	1
Total Cost of the system (USD)			23.13

Table II shows the list of the component used for this system [17]. Total cost of this system is USD 23.13.

VII. CONCLUSION

The main aim of this research is designing and implementing a low cost ECG monitoring system which has been fulfilled. We found the desired ECG signal and verified this to a doctor. Our designed system visualizes the ECG signal and heart rate. In our future work we will add abnormal ECG detection feature with this system. The cost of this system is only USD 23.13, which makes this system highly inexpensive and ideal for under developed and developing countries. The component used for this system consumes very low power and is takes maximum current of 65mA. We have tested this system and found that it is capable of functioning up to 22 hours by using smartphone. During operation only one core of the smartphone is used, for this in future multichannel feature can be added to this system. This system is an excellent choice for doctors and cardiac patients in developing countries like Bangladesh.

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