

Low Cost Microcontroller Based ECG Machine

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Abstract—Electrocardiographic (ECG) machine is an important equipment to diagnose heart problems. Besides, the ECG signals are used to detect many other features of human body and behavior. But it is not so cheap and simple in operation to be used in the countries like Bangladesh, where most of the people are very low income earners. Therefore, in this paper, we have tried to implement a simple and portable ECG machine. Since Arduino Uno microcontroller is very cheap, we have used it in our system to minimize the cost. Our designed system is powered by a 2-voltage level DC power supply. It provides wireless connectivity to have ECG data either in smartphone having android operating system or a PC/laptop having Windows operating system. To get the data, a graphic user interface has been designed. Android application has also been made using IDE for Android 2.3 and API 10. Since it requires no USB host API, almost 98% Android smartphones, available in the country, will be able to use it. We have calculated the heart rate from the measured ECG by our designed machine and by an ECG machine of a reputed diagnostic center in Dhaka city for the same people at the same time on same day. Then we calculated the percentage of errors between the readings of two machines and computed its average. From this computation, we have found out that the average percentage of error is within an acceptable limit.

Keywords—Low cost ECG machine, heart diseases, remote monitoring, Arduino microcontroller.

I. INTRODUCTION

IN today's health sectors, to diagnose the problems related to cardiovascular diseases, electrocardiographic machine is a vital tool. Without the help of this machine, the doctors and health professionals are unable to detect the heart related problems of human body. However, this machine is very costly in most part of this world. This modern world has around 17.65 million peoples who have a great chance of getting attacked to Cardiovascular Diseases (CVDs) [1]. CVDs are a group of ailments of the heart and blood vessels, such as, coronary heart disease, cerebrovascular disease, rheumatic heart disease etc. This group of diseases has become the number one cause for death worldwide. Heart disease is not only the main cause of premature death in most of the countries in the world but also the cause of early disability of people. Moreover, due to the rise of the elderly population in the world, the number of cardiac deaths is gradually growing. Four out of five CVD deaths occur as because of heart attacks and strokes, and of them, one third

occurs early in the people having age limit less than 70 years. It has been estimated that 17.9 million people died in the world due to CVDs in 2016, which is 31% of all deaths around the globe [1]. On the other hand, 85% of those deaths occur for the cause of heart attack and stroke. In 2015, it has been figured out that the 17 million non-communicable disease deaths occurred to the people with age limit less than 70, and 82% of them came from the people of low- and middle-income countries. It has also been reported that among these deaths, 37% were due to CVDs [1].

In today's biomedical engineering field, there are so many types of machines and equipment as well as methods and techniques to diagnose heart related diseases, for example, ECG, echocardiogram using ultrasound, cardiac magnetic resonance imaging (MRI), cardiac computed tomography (CT) scan, positron emission tomography (PET) scan, angiogram etc. Amongst these, ECG is the most common diagnosis method, and it can be applied in a wide area. Cardiologists or doctors can detect the heart problems or functionality from the various ECG parameters of the graphs. Therefore, its efficient determination is necessary to detect and thus to provide necessary treatments to the different kinds of patients having heart diseases. ECGs are also used in various types of detection, for example, drivers' lousiness or fatigue [2], [3], fetal information extraction [4] etc. ECG data can be used to identify efficiently several types of diseases, such as, right bundle branch block, myocardial infarction, sinus tachycardia, sinus bradycardia, coronary artery disease etc. [5], diabetic detection [6]. ECG has also been used to identify human beings from their physical activities based on support vector machine algorithm [7], to monitor patients from remote places [8], to monitor the other physical activities, for example, resting, walking, moving etc. [9].

In light of the above contexts, enormous endeavors have been applied to facilitate the best healthcare services at an affordable expense during the last few decades. With the rapid advancements in engineering and technological fields, it has become feasible to design and develop more efficient, reliable and affordable biomedical machines and equipment with new additional but important features. This has also made these biomedical machines more user-friendly. CVD related signs and symptoms can now be obtained in smart mobile phones or similar devices which are portable and wearable [10]. The prime objective of adding these functionalities are to help and support the doctors to monitor their patients' conditions through an automated and low cost system. However, this machine is still not so cheap to the people of the under-developed or developing countries. Moreover, doctors and medical staff are not physically available to all required places throughout the country. Therefore, it would be supportive if it is possible to design and build a system for the peoples of

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these countries to observe their heart conditions at an affordable cost from remote places. The biomedical engineers should find a way to address these problems and find suitable solutions for low cost ECG machine so that the physicians can keep track of the blood pressure, heart rate and pulse of a patient by pressing keypad considering exactly what should be normal and abnormal values. This will certainly decrease their on-site visiting time.

The Arduino microcontroller is a very cheap and readily available in the market and requires fewer efforts for its programming to automate the system. Also these are used in various biomedical and other similar applications due to its compactness, portability, less power consumption, enhanced battery life, high operating speed etc. [11]-[14]. This Arduino microcontroller with analog interfacing circuits, sensors, electrodes, amplifier, sampler and filter can acquire the very weak signal from the chest and send it to the microcontroller's output port in appropriate format. Then a set of programming instructions inside the microcontroller detects the arrhythmias, P, Q, R, S, T waves, QRS complex of the ECG signal, heart muscle necrosis, hypertrophic ventricles, position dependent variations of the heart rate etc.

II. LITERATURE REVIEW

In the literature, ECG machines were found to be designed and developed by many researchers around the world for several purposes. One such purpose was to fulfill the family requirements of ECG monitoring machine. For this, the researchers proposed an ECG monitoring system utilizing wireless sensor network for data transmission to facilitate the users. Basically, this was a human machine interface system based on Labview software. Thus its procedures and usages become user friendly [15].

In Shanxi Province of China, a hospital is utilizing a web based service called TeleECGService to get ECG data of the patients from a diagnostic center situated in a remote place. This system was designed and implemented for the direct interaction between the ECG machine and the center. This machine is found as highly interoperable [16].

Another new portable ECG monitoring system is designed and implemented based on MCU ARM Cortex-M3 with a high capacity SD card as the storage medium. This is able to realize user-machine interaction, waveform replay, arrhythmia analysis and illness alarm as well as to detect QRS wave and analyze real-time ECG data and also can embed file to store the ECG data in convenient text format [17].

An energy efficient ECG machine was designed and implemented and it was observed that it consumed less power than its out-of-date corresponding ECG machine, just 4.92 mW of power. It also reduced the cost of medical treatment. The design of ECG machine used different I/O standards, such as, LVDCI (Low Voltage Digitally Control Impedance), SSTL (Stub Series Terminated Logic) and HSTL (High Speed Transistor Logic). 98.6% power reduction was observed when ECG design is switched from SSTL2_II_DCI to LVDCI_DV2_15 I/O standard [18].

Microcontroller based devices are found reliable and

portable in biomedical electronics devices, like wearable and implantable devices, such as, pacemakers, ECG machines etc. Microprocessor technology has been employed in ECG machines to remove artifacts, baseline wander, etc. using software techniques [19].

Researchers have also concentrated on the use of number of leads in the electrodes of the ECG machine. For example, a few researchers have used 3-lead ECG electrodes [20]. On the other hand, a few have used either 5-lead [21] or 2-lead [22] ECG electrodes. These are also manufactured using various types of materials. One such example is a wearable 12-lead ECG fabric electrode [23], [24]. These were developed to process the ECG signals obtained from several positions of the body simultaneously. In this case [24], the fabric electrodes are attached to the wearable T-shirts, which would provide comfort and convenience to the patient while ECG signals' acquisition. From the measurement of entropy of ECG signals for both fabric and metal electrodes, it was found that the fabric electrodes can provide similar results as compared to the gelled metal electrodes. This finding eliminates the selection of electrode position before each use and the use of the conductive gels, which is not comfortable to the patients. Moreover, one can wash the electrodes after use and re-use it.

Another recent technology is the Internet of Things (IoT). Biomedical engineers have found the application of IoTs in the medical test and measurement systems as well. One such system has been found where it is proposed to monitor the ECG of the patients located in a remote area using IoT. In that system, IoT is used to collect the ECG signals from the patients' body through various sensors. Then the essential treating is accomplished in the microcontroller. After that the data are sent to distant cloud- Bluemix to be analyzed by an expert physician. The Bluemix cloud uses MQTT (Message Queuing Telemetry Transport) lightweight protocol, developed for a machine to machine (M2M) communication, to connect different types of applications and devices together placed at the various regions in the world [25].

Digital Signal Processing (DSP) techniques are being used in many applications of power electronics system [26]. Now this technique has been applied in detecting the important information of ECG signals by observing it in the monitor with the aim of assisting the physicians or cardiologists [27]. For real time visual observation of the acquired ECG signal from the human body on the graphical screen, such as, LCD, LED or PC monitor, it is imperative to confirm the stability and consistency of the collected ECG signal. Digital signal processing algorithms with Fourier and wavelet spectra are used for ECG diagnostics of CVD patients [27]. This would assist the cardiologists or physicians for accurate analysis and diagnosis of the disease and its magnitude. Besides, the DSP hardware based system has been designed and implemented using the digital signal processor with memory, signal display system and analog interfacing circuit [28], [29]. This type of system with DSP has the ability to operate as stand-alone and to update the data in real-time according to the on board pre-program algorithm for ECG analysis [30].

III. SYSTEM DESCRIPTION

A. Hardware Design

To design a hardware circuit to capture the ECG signal, we need to understand the basics of ECG waveform generation. The main function of the heart muscle is to pump the blood through various arteries and receive blood from various veins of the human body. In doing so, when the heart contracts or expands due to receiving the command signal from an electrical stimulus in its electro-conduction system, it generates the ECG signal. Thus ECG actually measures the functionality of the heart muscles in terms of electrical signal, which is periodic with respect to time. The heart of every living human body pumps blood when the muscles of the heart's wall are squeezed and thus causing to produce action potential, which then forms electrical current that flows from the heart throughout the entire body. Since the path resistance of the body is different, this current while flowing throughout the body creates the electric potential differences between various places of the human body. These potential differences can be detected and recorded using electrodes at the body surface. The electrical potential signals thus produced due to the contraction and relaxation of the heart's atrial and ventricular muscles are called the depolarization and the repolarization respectively. When atrial contraction occurs, depolarization begins giving rise to the P wave of the ECG signal. A QRS complex wave of ECG is generated when the atrial repolarization and ventricular depolarization take place. Finally, a T wave of the ECG signal arises when ventricular repolarization starts. A normal ECG wave form of a healthy person is depicted in Fig. 1 [28].

A hardware circuit is designed consisting of ECG electrodes, ECG sensor, amplifier, sampler and filter circuit, Arduino Uno microcontroller, laptop, smart phone, DC power supply etc. The complete hardware system is depicted in the block diagram of Fig. 2. To obtain the ECG signal, a 3-lead electrode is used. This is basically a set of transducers that are placed at some specific locations of the body of the patient to

collect the electrical activity of the heart. Since nerve and muscles are electrically active, and the heart can generate electrical current and voltage signals of very low amplitude these are sensed by the ECG sensor (AD8232 IC), but cannot be detected by the microcontroller. Of course, this is an analog signal as well. Therefore, it is then amplified by the amplifier and sampled by the sampler to convert the analog signal to Pulse Amplitude Modulated (PAM) signals of sufficient amplitude. Then a filter circuit is also used to remove any noise stemming from any part of this analog interfacing circuit or signal collecting electrodes. After getting these PAM signals, the microcontroller converts it into the appropriate digital signal through its processing algorithm, produces the ECG wave form according to the developed software and sends the signal to the display system connected to it through its output port. The form of ECG plot is processed by the software loaded into the PC or laptop or smartphone known as Graphical User Interface (GUI). The power supply unit has two DC voltage levels (5 V and 9 V) required for the ECG sensor and microcontroller IC as shown in Fig. 2.

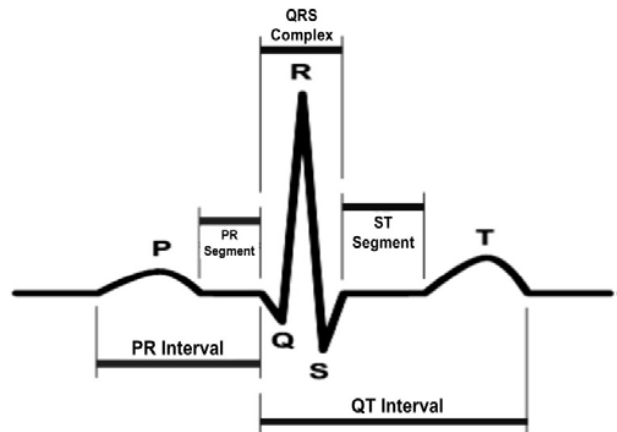


Fig. 1 A normal ECG wave form of a healthy person [28]

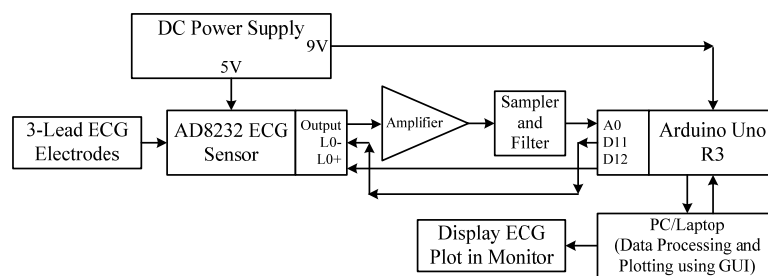


Fig. 2 Block diagram of the designed ECG machine

The waveform representation of the bio-electric potentials captured by the ECG electrodes and then processed by the Arduino microcontroller is called the ECG. This waveform can be viewed and printed out on a special type of ECG paper from the PC or laptop or smartphone by the user. The ECG paper is made up of small squares each with 1 mm by 1 mm in size. Therefore, the design and implementation of an ECG

machine should be done in such a way that it can recognize and record the bio-electric activities within the heart muscles. In each instant of time, stimulus is taken from the skin of human body and a time dependent patterns are emerged in the form of a wave and thus a number of connected waves make the ECG signal as shown in Fig. 1.

For ECG monitoring system, few features of the modern

smartphones are used, such as, high speed signal and data processing, Bluetooth connectivity that is based on IEEE 802.15.1 standard, Wi-Fi connectivity as per IEEE 802.11 standard, 3G/4G/5G standards of mobile phone technology, Android operating system etc. Use of these in-built features of smartphones has made it possible to implement the ECG monitoring system at a very low budget.

Arduino Uno R3 microcontroller is used in this work due to its several features, such as, low power consumption, high efficiency, in-built ADC and communication in USART mode. In-built ADC is used to convert the PAM signal into digital format. Serial data transmission feature is used to transmit and receive the ECG data to and from the outside of the microcontroller respectively. To transmit the data in serial communication mode, we selected the baud rate of 9600 bps and sampling rate of 320 samples/s. Arduino Uno's pin numbers 1 and 0 are connected to the Bluetooth module's Rx and Tx terminals for transmission and reception of signals respectively. We used HC06 Bluetooth module in between the Arduino Uno and Android smartphone. To communicate between the Arduino Uno microcontroller and the laptop or PC, USB port and cable are used.

The ECG signal acquisition is performed by detecting bio-electric potential signal on the skin surface through 3-lead transducers made up of Ag-AgCl electrodes. The acquired signals are then passed to the amplifier circuit. However, the quality of the collected ECG signal is degraded at the skin-electrode and connecting leads-amplifier interfaces as well as due to the motion artifact, interference, noise, input signal variation etc.

Another important block of this system is the amplifier. We have used the instrumentation amplifier IC numbered AD620 because of its low cost, high accuracy, high CMRR (> 100 dB) etc. To achieve the high gain over 700, 2-stage amplification has been performed. This reduces the hazard of amplifier being saturated. To get the gain, we used (1) [31]:

$$\text{Gain} = 1 + \frac{49.4}{R_g} \quad (1)$$

In the first stage amplifier, the target gain level was 16. Therefore, from (1), we have found that we need a resistance value for $R_g = 3.3$ k Ω . In the second stage amplifier, a non-inverting op-amp based IC is used and the target gain was 47. Thus, we achieved an overall gain of $16 \times 47 = 752$.

To eliminate any noise from the original signal, passive first order filters are used in this system. At first, a high pass filter with cut off frequency of 0.028 Hz is used to eliminate the high frequency noises. Then a low pass passive filter with cut off frequency of 144.7 Hz is used to eliminate the low frequency noises. To calculate these cut-off frequencies of passive filters, we used (2):

$$f_c = \frac{1}{2\pi RC} \quad (2)$$

To get the desired cut-off frequencies, we used the values

for resistances and capacitances as $R = 120$ k Ω ; $C = 47$ μ F and $R = 1.1$ k Ω ; $C = 1$ μ F for the high and low pass passive filters of the first order respectively. Actually these two filters are cascaded to have a passive band pass filter.

The two levels of DC power supply voltages of 9 V and 5 V are designed using the voltage regulator ICs LM7805 and LM7809. A center-tap transformer along with diodes are used to step down the power line AC voltage of 220 V with 50 Hz frequency and then to rectify the signal. To smoothen the pulsed rectified signal and to eliminate any DC offset signals two more capacitors having capacitance values with 1 μ F and 470 μ F are used at the input and output terminals of both the regulator ICs respectively. The use of capacitors also help to eliminate any power line frequency related and other noise interferences to the microcontroller.

B. Software Program Design

Since this system uses microcontroller, we need to develop software program as per logic required for the program. Arduino microcontroller uses assembly language program. At first, we need to identify what function this program should perform. We need two types of programming- one is at the layer of the device and the other is at the layer of the application. At the device layer, we need a program that would be capable of driving hardware of the system. However, at the application layer, the program must be able to display the ECG signal in appropriate format at the designated display device. For microcontroller programming, an integrated development platform is used. The flow chart of the developed program is shown in Fig. 3. This program reads the sensor data at the inputs of the microcontroller. Then the data are processed inside the microcontroller as per instruction sets of the assembly program and then sent to the output port for displaying the data in a suitable format.

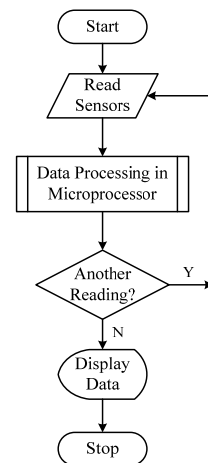


Fig. 3 Flow chart of the program of the designed ECG machine

To display the ECG signal at the designated display unit (for example, PC monitor, laptop or smartphone screen), an Android application or a software for laptop/PC is needed to be developed. The tasks of this application or software are to

process the data to display it in appropriate format in time scale. The algorithm for this program is shown in the flow chart of Fig. 4. It reads the data available at the port at every instant of time and creates the plot of ECG waveform based on the ADC values with respect to time. The programs are written using an open source programming language in the integrated development environment. We have used the necessary built-in libraries to receive and process the data. To display the ECG signal's waveform, we used several other functions. To store the ECG signal, we have used another function, which creates a text file and saves the numerical values obtained from the ADC of the microcontroller in this text file.

The complete system of the designed ECG machine with its electrodes is shown in Fig. 5.

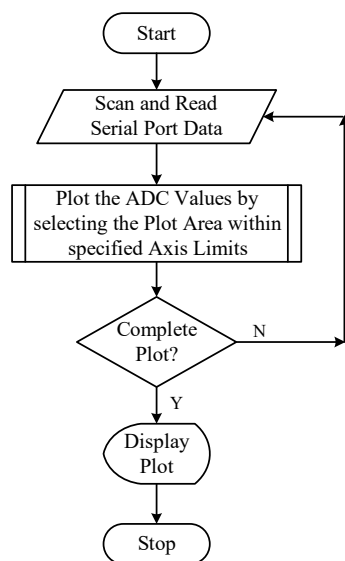


Fig. 4 Flow chart of the program to display ECG signal



Fig. 5 Complete set-up of the designed ECG machine

IV. RESULTS AND DISCUSSIONS

After completing the design of the ECG machine, we have tested it on several persons with or without any heart problem. But before doing the experiment, we have taken the necessary written permission from each of them. We have developed a questionnaire set for them about its use and purpose. They had to fill-up it with answers. We have measured the ECG signal and recorded its data. Then we have displayed it in our laptop screen as well as in smartphone screen. At the same time, we took the ECG waveform of the same people from a reputed diagnostic center where the machine produces very accurate results as per doctor's suggestions. The ECG waveforms obtained from a diagnostic center and by our designed ECG machine are given for two people in Figs. 6 and 7 respectively.

From the obtained data of both the machines, we have calculated the heart rate to compare the accuracy level of our designed ECG machine with respect to that of the diagnostic center's machine. We know when the heart rhythm of a person is regular then his heart rate (defined as the number of beats per minute, bpm) can be computed by dividing 300 by the number of big squares in between the two consecutive QRS complexes. For example, if we get 5 big squares in between the two consecutive QRS complexes then the heart rate of that person would be equal to $300/5 = 60$ bpm.

In Table I, we have shown the calculated heart rates (HRs) from both the ECG data of the diagnostic center's machine and our designed ECG machine's ADC values. Then we have calculated the percentage of errors using (3) and have shown them in Table I as well.

$$\text{Percentage of Error} = \frac{\text{HR from ADC} - \text{HR from ECG}}{\text{HR from ECG}} \times 100 \quad (3)$$

Then we have computed the average of these values and have found out that it is only around 7.5%.

TABLE I
DATA OF HR VALUES AND PERCENTAGE OF ERRORS FOR VARIOUS PEOPLE

Person	Age	HR from ECG	HR from ADC	Error in %
P1	26	58	63	8.62%
P2	25	71	76	7.04%
P3	26	65	70	7.69%
P4	25	68	73	7.35%
P5	27	72	77	6.94%

In Table II, we have shown the cost breakdown of the designed ECG machine and in Table III, we have shown the costs of various ECG machines available in the market.

TABLE II
COST BREAKDOWN OF THE DESIGNED ECG MACHINE

Sl #	Component Name	Quantity	Unit Cost (BDTK)	Cost (BDTK)
1	Arduino Uno R3	1	505	505
2	Sensor	1	440	440
3	AD8232	1	1000	1000
4	Other components	-	-	350
5	Installation Cost	1	1	500
Total Cost				2795

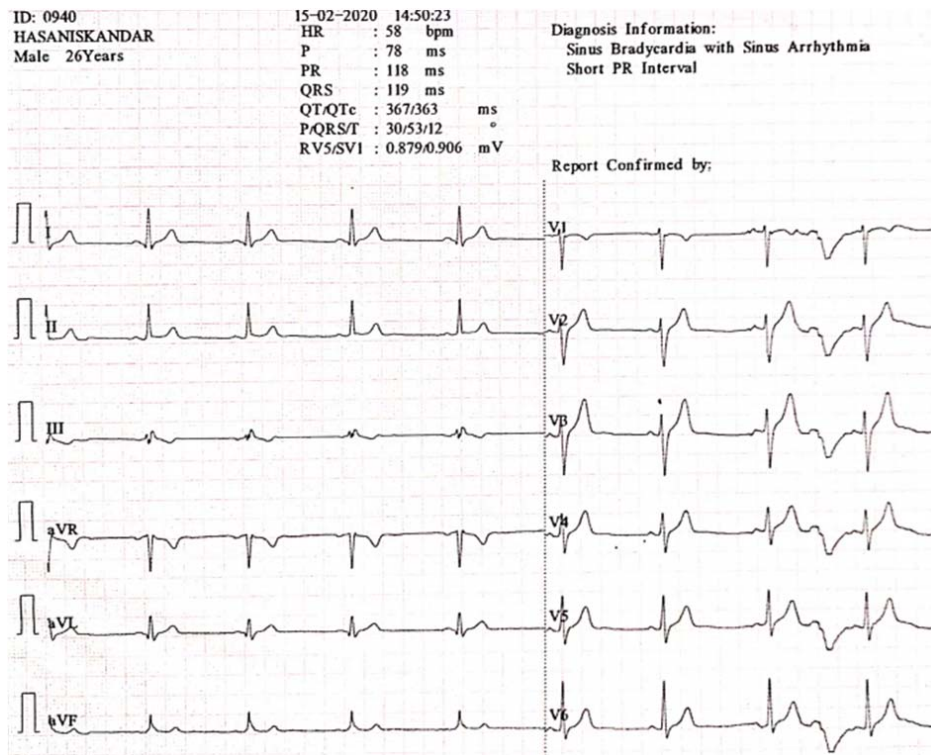


Fig. 6 ECG of person-1 obtained from diagnostic center

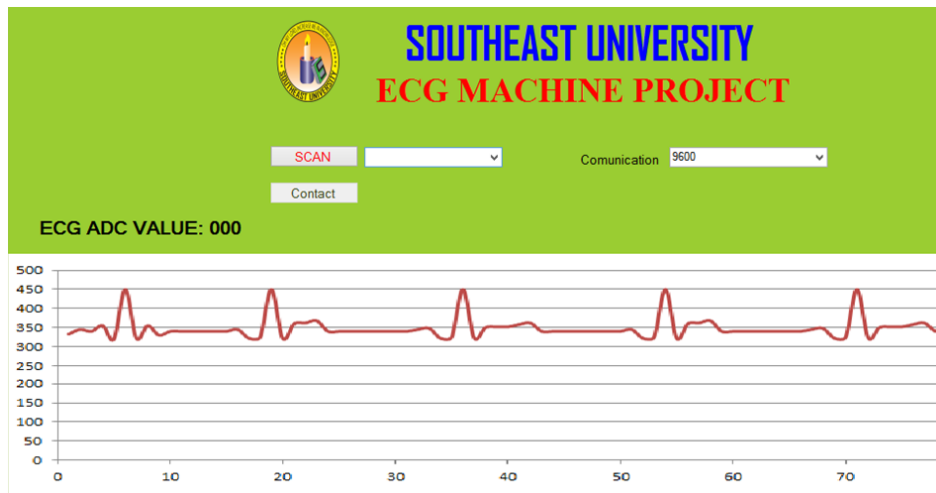


Fig. 7 ECG of person-1 obtained using our designed machine

TABLE III
COST BREAKDOWN OF THE DESIGNED ECG MACHINE

Sl #	Company Name	Quantity	Price (BDTK)
1	Technocare Meduisystems	1	42500
2	K-Life	1	30000
3	China Dongjiang	1	22400
4	Our proposed machine	1	2795

From Table III, we see that the design and implementation cost of our designed ECG machine is very cheap with respect to the ECG machines exported from foreign countries. So, if we can use this machine, we can save foreign currencies as

well as we can make it available to the mass people at an affordable cost but not compromising the quality or accuracy of the ECG data too much.

V.CONCLUSION

We have designed and implemented a robust, low cost ECG machine based on microcontroller having the features of connecting it to the smartphone. The system is portable and no on-site visit is required to monitor the ECG of a patient in real time. The system requires a laptop or PC or smartphone that are being used by the physicians or medical staff to observe

the processed ECG data with respect to time variation. Therefore, this system can be placed in a remote village to capture the ECG of a patient residing there and the doctor can prescribe the patient proper medicines or other advices by observing the ECG residing at his/her own place. That is, neither doctor nor the patient needs to move from their respective places. However, there are a few scopes for further development or improvement of this designed system. We recommend the following future plans for this system:

- To design an interfacing circuit with an LCD screen to make it more portable. Because, all the patients may not have the PC or Laptop or smartphone and in some villages the network connection may be very poor.
- To design a rechargeable battery for the ECG machine.
- To develop a program for auto-reporting of the patient.
- To develop an application for the smartphone for real-time analysis.
- To design and implement the system on a printed circuit board for housing it inside a box safely.
- To improve the algorithm of the ECG signal detection so that more parameters of the ECG signal can be extracted.
- To optimize the components and circuits to make more cost-effective, efficient and reliable.

However, through this work, our main goal to provide a simple, portable and cost effective solution for the ECG signal monitoring and HR computation for the remote village areas of Bangladesh was successful at by and large.

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