Design and Implementation of a Portable ECG Device

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ABSTRACT

Electrocardiography(ECG) is the technology of measuring the electrical changes of the heart. The electrical change is due to the depolarization and repolarization of the heart cells which produces a specific wave or complex. The potential developed is captured by the electrodes placed on the skin, which ranges in micro to millivolts. Weak signals captured by the electrodes are amplified and converted into a voltage that is readable for microcontroller ATmega328P. ECG is represented by the waves called P, QRS, and T waves. One cardiac cycle of the heart consists of P-QRS-T waves in ECG. The amplitude of the waves, complexes, and the time interval between different waves or segments conveys the total information on the working activity of the heart. A proper study of those waveforms and time intervals on ECG aids to determine and diagnose different cardiac abnormalities. This paper presents a method of extraction of voltage generated during cardiac movement of the human body using an electrode, amplifier, microcontroller and OLED screen. It describes the method of calculating heartbeats per minute from the ECG signal and displays beats per minute on the same OLED screen.

Keywords: Beats per Minute, Electrocardiogram, Integrated Development Environment, Inter-Integrated Circuit, Organic Light Emitting Diode

1. INTRODUCTION

Heart is a muscular organ whose size is about the human's fist that helps in the circulation of the blood throughout the body. It is divided into 4 chambers: Left atrium, Right atrium, Left ventricles, and Right ventricles. Deoxygenated blood from the whole body passes through the right atrium and right ventricles to the lungs. Oxygenated blood from the blood passes to the left atrium and left ventricles, from which it passes out to the different tissues of the body [1].

Cardiac cells are the muscle cells that make up the heart muscle. Cardiac cells consist of a difference in charge inside the cells, compared to the outside of the cells. In their resting state, cardiac cells are electrically polarized. Inside of the cells is negatively polarized with respect to their outside of the cells. There is a distribution of ions in our body such as (primarily potassium, sodium, chloride, and calcium) which keeps the inside of the cells electronegative with comparison to the outside of the cells. These ions pass in and out of the cells by the special channels of the cell membrane. In the process of depolarization, cardiac cells can lose their internal negativity. In pacemaker cells, depolarization occurs voluntarily. Positive ions like Na+ pass into the cells through the channels of the cell membrane which creates positivity of the charges inside the cell compared to the outside of the cells. The wave of depolarization is propagated to all the cells of the heart since the heart muscle is made up of the groups of those cells. This wave of depolarization represents the flow of electricity in the heart, an electric current. After the wave spreads over the heart, potassium ions (K+) starts to flow out of the cells from potassium channels. Simultaneously, calcium ions (Ca+) moves inside of the cells maintaining depolarization. With the intervene of the calcium ions in the cells, this acts as a stimulus for the contraction of the heart. Hence, depolarization precedes the contraction of the heart.

After depolarization is complete, the cardiac cells restore their resting polarity through a process called repolarization. Repolarization is completed by the reverse flow of the ions. In this process, K+ ions move out of the cardiac cells through the channels of the cell. This results in a decrease in the positivity of the charges in the cell. To restore into its rest state, the cell should have its internal negativity. For this purpose, Na+ ions should exchange their location from inside to the outside of the cells whereas K+ ions should change their location from outside to the inside of the cells [2].

An enzyme called N+/ K+ ATPase(sodium-potassium adenosine triphosphatase) is found in every human body. It is located on the membrane of every cell which deals with the exchange of ions in and out of the cells [3]. It maintains the potential of the cells for the resting state. To keep the potential of the cells, Na+/ K+ ATPase pumps 2 potassium ions in the cells and moves 3 sodium ions out of the cells. This process occurs simultaneously on every cell of the heart, which results in the resting state of the heart where there is the presence of internal negativity in the cells.

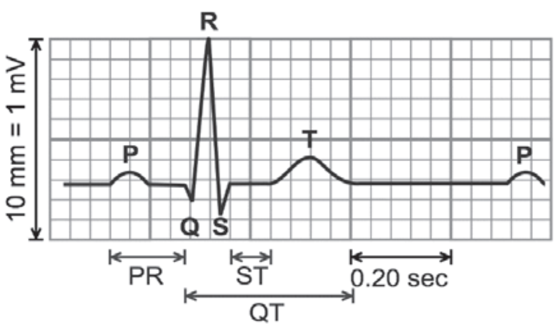

Figure 1: EKG wave and complexes

The electrocardiogram (ECG or EKG) is a graphical recording of the heart electrical activity during each of its cycles. It is a graph of the electrical activity of the heart during cardiac movement plotted as voltage versus time. Electrodes are placed on the skin to detect the electrical activity of the heart. The contraction and relaxation of the heart muscles are associated with a change in the electrical charges. These changes can be tracked down by the help of the electrodes placed on the skin of the body.

A spread of the electric currents throughout the cells of the heart is the signal of the cardiac contraction. These signals are generated by the pacemaker cells too. The electrical currents start from the sinoatrial (SA) node which is located on the right atrium of the heart. This node is a collection of the cells that spontaneously generates the electrical stimulus. This node is therefore known as the pacemaker of the heart. The wave of depolarization starts from the Sinoatrial node of the right atrium and spreads over the left atrium too. It reaches then to the fibrous septum that separates both atria from the ventricles. The electrical current or stimulus then reaches the atrioventricular (AV) node. AV node can also act as the backup pacemaker cell if the signal received is weak. AV node acts as the connecting path of the waves from the atriums to the ventricles. Thereafter, the depolarization waves travel from the AV node to the bundle of His which is located at the Interventricular septum. Bundle of His spread to the right and left ventricles. Finally, this helps in carrying current to the muscles of both left ventricles and right ventricles by their branches specially called 'Purkinje fibers' [4].

After, the spread of the current from atrial to ventricles, atrial and ventricles return into their original state which is resting state. This process produces a current which is recorded on the ECG. During those processes, different waves are generated at a different instance of time. Those waves are labeled as P wave, QRS complex, T wave.

P wave means the propagation of the charges through the atria, also called atrial depolarization. Similarly, the PR interval is the time taken by the stimulus to move from the atrial and pass through the AV junction. The QRS complex represents the flow of charges or stimulus through the ventricles, called ventricular depolarization. Q wave represents the depolarization of the Interventricular septum. R wave corresponds to the ventricular depolarization through both ventricles. S wave represents the depolarization of the ventricles to the base of the heart. The T wave and ST segment represent the return of stimulated ventricles to the resting state [5].

There is no wave or complex that represents the return of stimulated atria to resting state because, in the meantime, ventricular depolarization occurs which has higher amplitudes, so the lower amplitudes of the atrial are not observed on ECG paper. The sequence of the P-QRS-T is a repetitive cycle, which corresponds to the electrical activity of the heart.

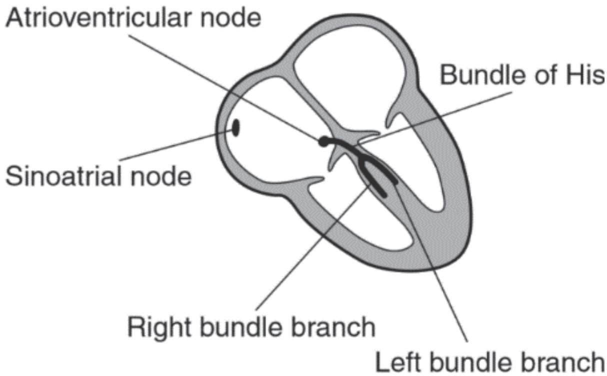

Figure 2: The wiring of Heart

2. RELATED WORKS

ECG has the history of more than 100 years of development, moving through the phases of invention, application on filed, and further development. The history of ECG could be tracked from the discovery of the electrical activity of the heart by Köllicker and Müller in 1856. The first ECG of a human being was recorded with a siphon instrument in 1869 or 1870 by Muirhead in London. The use of five electrodes for ECG measurement was developed by Augustus Waller. It used capillary electrometer to record the human electrocardiogram. Einthoven made a breakthrough in ECG technology with his invention of the string galvanometer that could measure ECG signals in1901. Later he proposed the theory of the three electrodes in 1906 in terms of the triangle, called Einthoven's triangle that is still used to record the ECG. Sir Thomas Lewis invented Lewis lead electrode that helps to detect the atrial and ventricular activity. Dr. Taro Takemi invented the new portable ECG machine in 1937. In 1938, The American Heart Association and the Cardiac Society of Great Britain pulished their recommendation of recording the heart beats formed by the six unipolar leads on the precordium. Norman Holter invented the dynamic ECG called Holter ECG that enables the continuous monitoring of the electrical activities of the heart for more than 24 hours. This helps in analyzing the arrhythmias and determining the size of the myocardial ischemia. Robert Zalenski and his

collegues pulblished an article the use of 15- lead ECG for the diagnosis of acute coronary syndromes. In 1999, researchers from Texas transmitted the 12- lead ECG through wireless technology to computer. In recent years, innovation in this technology has been continuously increasing, such as the invention of the 4- dimensional (4-D) ECG and remote ECG monitor.
Advanced ECG machines have a high price range so, they seem to be unaffordable to the clinics in rural areas. ECG designed by us is cheaper and portable too. Small clinics can be able to purchase it so they can detect the heart-related abnormalities. Students related to the medical field also can use this ECG device for the study and demonstration of ECG signal.

3. HARDWARE REQUIREMENTS

3.1. ELECTRODE SENSOR

First, we must detect the small electrical changes on the skin which is caused due to depolarization and repolarization during a heartbeat. Electrodes are used to detect the electrical changes. Generally, electrodes are made up of silver or silver chloride because it has a high cut off frequency, provides stable potential and potentiality of miniaturization. They offer low skin-electrode interface impedance and considered as non-polarizable electrodes [6]. Conductive and adhesive hydrogel used in electrode helps to improve the conductivity. The placement of the three electrodes is on the right arm, left arm, and right leg. The electrode placed on the left arm provides positive input to the instrumentation amplifier of AD8232 whereas the electrode placed on the right arm provides the negative input to the instrumentation amplifier of the AD8232. The electrode attached to the right leg acts as the ground for the ECG. The direction waveforms of the ECG depend upon the placement of the ECG in our body.

3.2. AD8232

AD8233 is a single lead heart rate monitor that measures the electrical activity of the heart. The electrical activity of the heart can be displayed as an ECG and the output of this device is analog. This device helps to extract and amplify the potential obtained from the heart. The operating voltage of the device is 3.3 volt. AD8232 has nine connection points. Shutdown (SDN), LO+, LO-, OUT, 3.3V, GND are essential pins that are used for the communication with the development board such as Arduino, Raspberry Pi [7]. Leadoff pins (LO+, LO-) are used for identifying which one of the electrode is disconnected by setting them high. It consists of pins for the left arm (LA), right arm (RA) and Right Leg (RL) pins to interact with the electrodes.

3.3 ATmega328P MICROCONTROLLER

ATmega328P is a 28 pin single chip microcontroller which is developed by Atmel. It is an 8- bit microcontroller based on the advanced RISC architecture. ATmega328P integrates 32KB in-system self-programmable flash memory with read/ write capabilities. It combines 1KB EEPROM and 2KB SRAM. It has 23 programmable generals I/O lines with 32 general-purpose working registers [8]. Its maximum working frequency is 20MHz. It provides programmable serial USART, SPI serial port, timers/ counters, and throughput up to 20 MIPS.

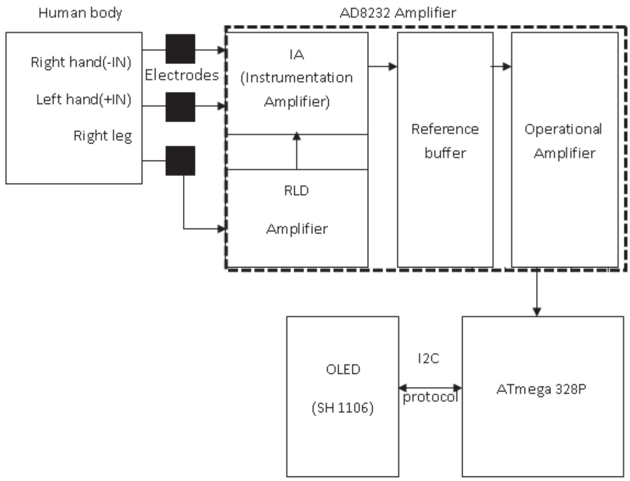

Figure 3: Block diagram of implemented system

3.4. 1.3 INCH OLED (SH1106)

SH1106 is a 1.3-inch display module with the SH1106 OLED driver module to manipulate and control its display its graphics in a dot-matrix graphics display system. It is made of up 128X64 pixels screen. It is a single color (monochrome) display system allowing each pixel to be on or off. It supports 3- wire/ 4- wire Serial Peripheral Interface (SPI) and Inter-Integrated Circuit (I2C) interfaces. It is a common cathode OLED panel. Panel size of SH1106 is 34.5 mm x 23.0 mm x 1.4 mm. The size of pixel is 0.21mm x 0.18mm [9].

4. SOFTWARE REQUIREMENTS

4.1. ARDUINO IDE

The Arduino IDE is an open-source and cross-platform (Windows, Linux, and macOS) application which is written in Java. It is mainly used for writing, compiling, and uploading codes in different types of Arduino devices. It allows uploading codes on 3rd party development boards too. The main code written on this platform is converted into a Hex file before uploading it on the board [10].

5. SYSTEM DESCRIPTION AND IMPLEMENTATION

A prototype of ECG involves the computation and processing from the two major devices: Heart rate monitor (AD8232) and Microcontroller (ATmega328P). Electrodes are placed on the right arm, left arm, and right leg of the human body. The electrodes placed on both arms detect the electrical activity of the heart and measures the potential. Electrodes placed on the left arm acts as the positive terminal, right arm acts as the negative terminal and the right leg is used for the ground. The potential observed from the left electrode is subtracted to the potential observed from the right electrode. As a result, there is only one view of the electrical activity of the heart from the left electrode with respect to the right one and can be named as Lead I.

$$Lead\ I = Potentials\ of\ (Left\ arm - Right\ arm) \quad (1)$$

Hence, AD8232 is called a single lead heart monitor. When electrodes are placed on the skin with gel around the electrodes there is an electrode-electrolyte interface with the skin. Electrolyte gel containing Clis used as principal anion for maintaining conduction. There is a difference in the ionic concentration between the fluids of the body and electrolyte which permits the charge to pass through the electrode- skin interface. Therefore, the half-cell potential is developed, which helps to calculate the voltage induced in the electrical activity of the heart [11].

The signal detected by electrodes on the skin is of weak voltages and for the processing on Arduino, those voltages are amplified by AD8232 for the processing and readable voltage for the microcontroller, ATmega328P. AD8232 consists of an instrumentation amplifier, an operational amplifier, and a reference buffer. The instrumentation amplifier consists of two op-amps which are carefully matched. It is used for the amplification of the difference of signals from both electrodes. It offers CMRR of 80- 86 dB and offers the rejection of the common-mode signal transmitted through both electrodes. It is followed by the reference buffers which creates isolation between the instrumentation amplifier and the operational amplifier. It provides sufficient drive capability to pass signals to the succeeding stages in the circuit and protects the output of the succeeding device. Hereafter, there lies an operational amplifier which helps to increase the gain of the system and it boots the analog signal, ensuring it is readable by the further devices such as a microcontroller. The op-amp has a CMRR of 100 dB. AD8232 uses the right leg drive amplifier which is associated with the right leg electrode that acts as a ground to the system. It inverts the common-mode signal that is present at the inputs of instrumentation amplifier and helps to improve the CMRR of the system. The op-amp used in the right leg circuit saturates if any high voltage appears in the circuit and removes the ground system from the patient.

The signal is also amplified to the readable format from the AD8232, which is then passed to the ATmega328P. 3.3V of AD8232 is connected with the 3.3V to power on the microcontroller. Similarly, the output of AD8232 is connected to the A0 pin of the microcontroller. The A0 pin converts analog signals to the digital signals and is capable of passing an analog signal for further processing to the microcontroller.

SH1106 OLED is interfaced with ATmega328P for displaying the ECG graph in monochrome color. SH1106 includes VCC, GND, SCL and SDA pins. According to the wire library of Arduino, the A4 pin is connected to the SDA pin and the A5 pin is connected to the SCL pin of the OLED module. Similarly, VCC is connected with the 5V pin and GND to the ground pin of the microcontroller. Both devices communicate with each other based on the I2C protocol. This protocol uses two wires for connection between the master and slave devices. The microcontroller is a master device and SH1106 OLED is a slave device. Two wires, SCL and SDA are used to carry information between the devices. The timings and data transfer are generated by ATmega328P. SCL line is used to synchronize the start, stop, and data communication between devices.

ECG graph can be displayed by programming on the microcontroller using the library of the Adafruit. Library called Adafruit_GFX includes functions like clear Display( ), setTextSize(size), setTextColor(white), writeLine( ) are used for manipulating, controlling the signals obtained from the AD8232 for displaying it on the OLED displays. It provides common syntax and a group of graphics functions that can be applied on the OLED screen to design the display. The programming part has two sections which are setup and loop. The setup part aids into a clear screen of the display unit and sets text size whereas the loop section helps in generating the continuous data for designing and displaying ECG signals. As the screen resolution has 128 pixels on x- coordinates, once the value reaches the last pixel on the horizontal side of the screen it clears the screen and, coordinates of both x and y pixel are updated with the last coordinate value in the new screen. This is performed to generate continuous ECG signals on the OLED screen. Similarly, there are 64 pixels on the y- coordinates. The value of the y- pixel coordinates are normalized to set their values within the given limit of the pixels on the vertical side. Hence, now the ECG graph drawn on the OLED is continuous and fits on the area of the screen. Beats per Minute (BPM) is also calculated from the help of the ECG signal generated. It implements the Big Box method to calculate the BPM of the human heart. It is calculated by dividing 60 by the time taken by the signal to reach between two successive R waves. BPM is calculated as:

$$BPM = \frac{60}{Time\ instant\ between\ two\ successive\ R} \quad (2)$$

The equation (2) calculates Beats per Minute with the help of time instant between two successive R-wave.

6. RESULTS

Our designed system reads the value from the electrodes from the skin of the human body. Those signals are amplified by the help of AD8232 and passed to the ATmega328P. It processes the data and sends it to the display module OLED using the I^2C protocol for the communication between them. The waveform of the electrical activity of the heart is continuously displayed on the screen. For the analysis of the ECG signal, we have used the serial plotter of Arduino IDE. The serial plotter plots the analog ECG signal with the scaling for the analysis.

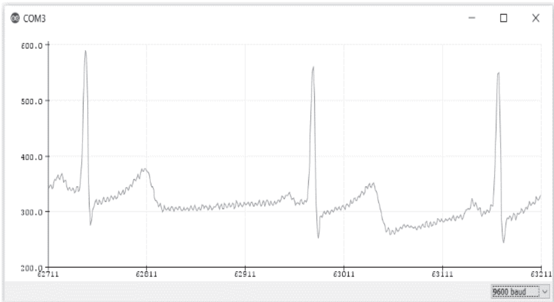

Figure 4: Output AD8232 signals in serial plotter

After the analysis of the signals from AD8232 by a serial plotter, it assures that the signal has been amplified and AD8232 is working properly. The data is plotted within the OLEDscreen by normalization of the signals.

Figure 5: ECG signal in OLED screen with BPM

ECG at serial plotter is more distinct and accurate than displaying it on the OLED screen. The effect of the error in the signal is seen when ECG plots on the OLED. Finally, BPM, calculated using the concept of (2) is displayed on the screen. Noise in the signal hampers in the generation of the smooth ECG signal. The different noises will occur in process of measuring ECG waves. Baseline wander is one of the noise in ECG which is of low frequency and is generated by the body movement, and respiration. Another noise is generated is due to electrode contact. The electrode- electrolyte- skin contact will also influence the signals of ECG. So, use of gel with electrode with proper attachment to the skin is required and high pass filter with cut off frequency 0.5 Hz can be implemented to remove the noise. Transducer noise can occur if other electrodes are used rather than Ag- AgCl electrodes. Instrumentation noise is another noise which can occur but, this noise cannot be eliminated. These are the types of noises which distorts the ECG.

7. CONCLUSION

ECG is becoming advanced with the aid of machine learning and wireless electrodes. Hopitals use 12- lead ECG to analyze the arrythmias of heart. But, our designed system is economical and portable which helps in the study for the students of the medical sectors for the general understanding of ECG. It can calculate heartbeats per minute.
As this project is just a basic project done by the group of undergraduate students there are many more things to work out on this project. Applications and services from this system can be extended to a certain level such as, an image of the ECG signal that can be stored which can be used for further uses. A beeper can be implemented that provides notification on the abnormalities observed in the ECG signal. It can be implemented for machine learning too. Implementation of the Wi-Fi module enables to share the image or data of ECG over any location so experts can analyze and give reviews. It can create a cooperative environment for the experts and physicians to give their opinions on the abnormal cases.

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REFERENCES

[1] A. J. Weinhaus and K. P. Roberts. [Online]. Available: http://eknygos.lsmuni.lt/springer/675/51-79.pdf. [Accessed 6 1 2020].

[2] J. Pinnel, S. Turner and S. Howell, Cardiac muscle physiology, vol. 7, no. 3, pp. 85-88, 2007.

[3] M. V. Clausen, F. Hilbers and H. Poulsen, "The Structure and Function of the Na,K-ATPase Isoforms in Health and Disease," The Structure and Function of the Na,K-ATPase Isoforms in Health and Disease, 2017.

[4] A. L. Goldberger, Z. D. Goldberger and A. Shvilkin, Goldberger's Clinical Electrocardiography, Elsevier Saunders, 2012.

[5] E. A. Ashley and J. Niebauer, in Cardiology Explained, 2004, pp. 19-21.

[6] J. G. Webster, Encyclopedia of Medical Devices and Instrumentation, 2006.

[7] "Sumrom Electronics/ Technologies," [Online]. Available: https://www.sunrom.com/p/ecg-sensor-module-ad8232. [Accessed 7 1 2020].

[8] "Microchip," [Online]. Available: https://www.microchip.com/wwwproducts/en/ATmega328p. [Accessed 7 1 2020].

[9] "Winstar," [Online]. Available: https://www.winstar.com.tw/products/oled-module/graphic-oled-display/sh1106-oled.html. [Accessed 7 1 2020].

[10] "The Engineering Projects," [Online]. Available: https://www.theengineeringprojects.com/2018/10/introduction-to-arduino-ide.html. [Accessed 7 2020].

[11] M. R. Neuman, "Biopotential Electrodes," in Medical Instrumentation Application and Design, New York, 2010, pp. 189-225.