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ECG Sensor Measurements with Arduino in Biomedicine Education

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Abstract: *This paper presents the system for electrocardiogram measurements (ECG) using an Arduino microcontroller and AD8232 ECG sensor. The paper gives the basics of human heart anatomy and electrical activity which is enough for understanding the basic principles of ECG measurements. The hardware and software components are presented, as well as the given results. This system can be effectively used as an ECG measurement device and in biomedicine students' education.*

Keywords: *Arduino; ECG; human heart; measurements; sensor*

1. INTRODUCTION

The use of computers in biomedicine has made a revolution in this field since it greatly facilitated diagnostic procedures, as well as the analysis of the obtained results.

Electrocardiography is certainly one of the pioneers of this field. Starting with bulky and heavy devices for registering heart activity, today it has come to the point that for some basic identification of the heart rhythm, it is enough to have a small and cheap sensor plate.

Of course, the question of the accuracy of such sensors remains, but they can be used for research, education, and even initial diagnostics. One of such sensors is also presented in this paper. How the sensor is integrated into a system that can successfully register the human heart is also described.

Authors of [1] and [2] used ECG sensor as wireless wearable device to be used in portable form. In [3], the authors showed the potential of medical-grade ECG sensor in medicine, sports, veterinary, etc. The development of wireless sensor network for ECG monitoring is given in [4]. ECG sensor and transmission of its data via Bluetooth LE is presented in [5]. A wearable system with wireless low power ECG sensor is given in [6].

The anatomy of the human heart is presented in Section 2. The heart's electrical activity is given in Section 3. Section 4 shows the electrocardiography methods. The hardware and software components of the system for heart activity detection are given in Section 5. Section 6 shows the results and corresponding discussion. Section 7 gives the concluding remarks, as well as the possibilities for system upgrades.

2. ANATOMY OF THE HUMAN HEART

The human heart is a muscle about the size of a man's fist weighing about 300 g. It consists of two separate, but mutually similar parts, which together act as a blood pump. The heart is divided by a muscular wall into left and right sides. Each side is divided into two parts - the smaller is the atrium, and the larger is the ventricle. Heart valves regulate the passage of blood from the atrium to the ventricle. They have the role of a valve: they let blood flow in one direction, from the atrium to the ventricle. The flow of blood passing from the atrium to the ventricle closes the heart valves, so the return of blood is not possible [7].

Between the atrium and the chambers of the heart, there are valves: mitral (which has two valves) and tricuspid (which has three valves). The valves function as sophisticated non-return "valves" that prevent blood from the ventricles from returning to the atria. The anatomy of the heart is shown in Fig. 1.

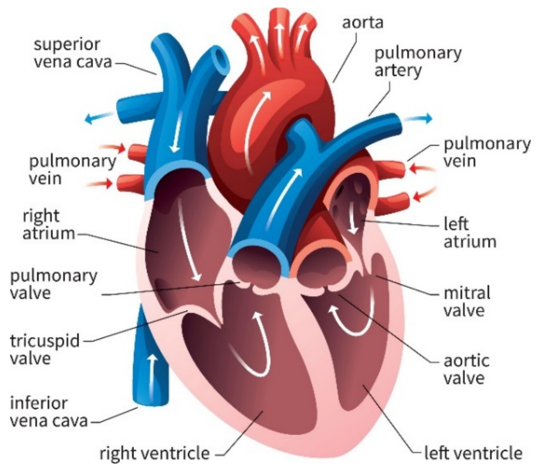

Figure 1. *The anatomy of the human heart [8]*

The left side of the heart pumps blood into the whole body, in all body cells. The right side of the heart pumps blood into the lungs. The blood of poor oxygen enters through the superior and inferior vena cava to the right atrium, crossing the right ventricle, and is squeezed into the pulmonary artery. The pulmonary artery is a large blood vessel, which later branches and flows the blood to the entire lungs. In the lungs, blood is re-enriched with oxygen and returned to the left side of the heart [9].

3. HEART ELECTRICAL ACTIVITY

All events that occur from the beginning of one beat until the beginning of the following are called a heart cycle [10]. Each cycle is caused by the spontaneous generation of action potential in the sinus node. The sinus node (often called a sinoatrial node) is a small flat ellipsoidal tape of the specialized heart muscle. It is located on the upper posterolateral wall of the right atrium just below and slightly lateral from the opening of the superior vena cava (Fig. 2).

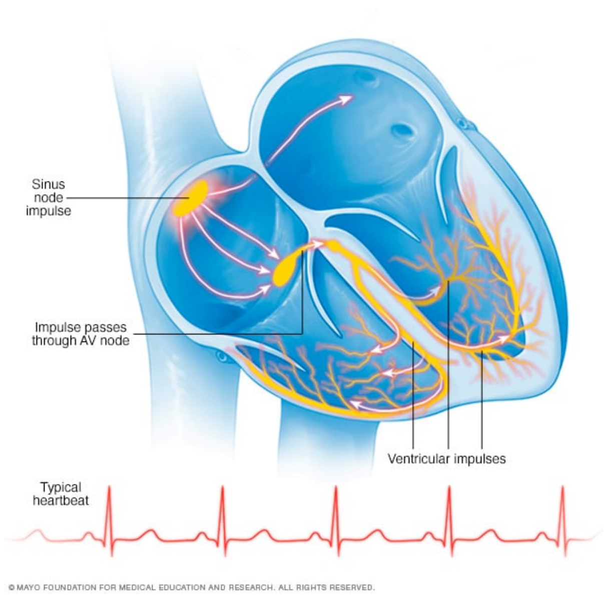

Figure 2. *The location of the sinus node [11]*

The muscle fibers of the sinus node are directly connected to the fibers of the atrium so that each action potential starting in the sinus node is momentarily spreading throughout the atrial muscular wall. For this reason, a sinus node controls the heartbeat.

Under normal circumstances, potentials are conducted only through a specialized conducting system called the "A-V" beam of conducting fibers.

All events that occur from the beginning of one beat until the beginning of the next are called heart cycle. Each cycle is caused by the spontaneous generation of action potential in the sinus node [9 – 12].

4. ELECTROCARDIOGRAM

When the heart impulse goes through the heart, the electricity is also spreading through the heart to the tissue surrounding it. A small part of that current comes to the surface of the skin. If the electrodes are put on the skin from the opposite side of the heart, the electrical potentials generated by the heart can be recorded. Such a recording is known as an electrocardiogram (Fig. 3).

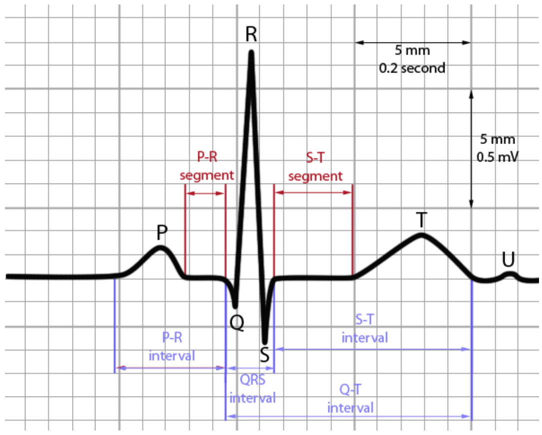

Figure 3. *Electrocardiogram [13]*

The characteristic parts of the ECG signal are P, Q, R, S, and T waves, and are shown in Fig. 3. QRS complex consists of Q, R, and S waves [9 – 13].

The P wave is an electric activity of contractions of both atria. The QRS complex is an electric impulse on the road from the A-V node to myocardial cells. The QRS complex represents the electrical activity of stimulated ventricles. The Q wave is the first descending part of the QRS complex and it is important to know that the Q wave is often not present at the ECG. The first rising wave followed after the Q wave is the R wave. After the ascending R wave follows the descending S wave. The difference between Q and S is that there is no rising wave in front of Q waves, and there is a rising wave in front of the S wave.

The T wave represents the repolarization of the ventricles so that they can be re-stimulated by electric impulse. This wave can be understood as a "reset" of heart cells. One heart cycle consists of a P wave, QRS complex, and T wave. This cycle is constantly repeated [9 – 13].

The U wave comes after the T wave and usually has the same direction. It may not be present always on ECG measurements, and its origin is still unknown [14].

5. SYSTEM FOR HEART RATE DETECTION

The backbone of this system is a heart rate detection sensor. On one side, it is connected by electrodes to the human body at exactly certain points, and on the other hand, with a microcontroller, which has the possibility of receiving data from the sensor. The schematic representation of the given detection system and the view of the heart rate is given in Fig. 4.

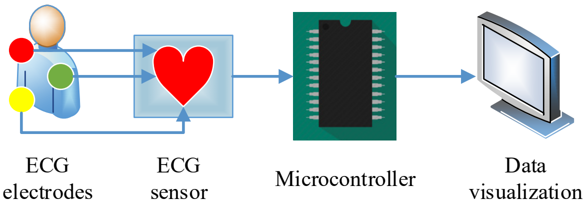

Figure 4. *Schematic representation of the system for heart rate detection*

As an ECG sensor, the AD8232 sensor is used [15]. The Microcontroller is an Arduino Pro Mini based on the ATmega 328 chip, which operates at a frequency of 8 MHz and a voltage of 3.3 V. It has 32 KB of flash memory, of which 2 KB is used for bootloader, as well as 16 input-output pins which can be used for different purposes.

5.1. AD8232 ECG SENSOR

The AD8232 is designed to extract, amplify, and filter weak biopotential signals in the presence of noise, such as noise from movement or distant electrode placement. This design allows the analog-to-digital converter or microcontroller to easily reach the output signals. The layout of this tile is shown in Fig. 5.

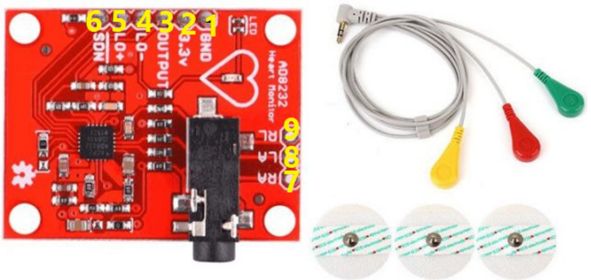

Figure 5. *The AD8232 ECG sensor plate with electrodes [15]*

The use of the corresponding pins on the AD8232 sensor board is shown in Table 1. In addition to the pins for connecting individual electrodes, there is also an input for connecting a cable with combined electrodes.

Table 1. *The use of the corresponding pins on the AD8232 sensor board [16]*

No.	Pin	Usage
1	GND	Ground
2	3.3V	Power supply
3	OUTPUT	Output ECG signal
4	LO-	The negative end of the circuit for detection of working interruptions (*Leads-off Detect*)
5	LO+	The positive end of the circuit for detection of working interruptions
6	/SDN	*Shutdown*
7	RA	*Right Arm* electrode
8	LA	*Left Arm* electrode
9	RL	*Right Leg* electrode

The AD8232 has a two-pole high-pass filter that removes noise due to movement and the very potential of the electrodes. This filter is connected to the instrumentation architecture of the amplifier which enables high gains and high-pass filtering in one step, thus reducing the cost and also the space on the chip. This ECG board also has a three-pole low-pass filter, which removes additional noise, as well as a circuit for quickly detecting interruptions in the signal due to the removal of electrodes from the body [16].

5.2. ECG ELECTRODES PLACEMENT

The electrodes that came with the ECG sensor are colored yellow, red, and green. The place of connection of these electrodes on the body is given in Fig. 6.

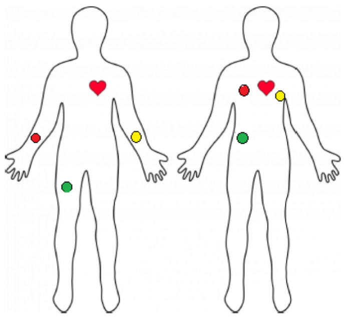

Figure 6. *Points of connection of ECG electrodes to the body [17]*

As can be seen from Fig. 6, the yellow electrode is attached to the left hand, but it can also be on the left side of the heart. The red electrode is attached to the right hand, and can also be attached to the right side of the heart. The green electrode is attached to the right leg, and can also be placed under the heart on the right side.

Based on all of the above, Fig. 7 shows how heart activity was measured by placing electrodes in appropriate places.

Figure 7. *Position of ECG electrodes on the patient's body*

6. RESULTS AND DISCUSSION

The software part of the system consists of an Arduino program and a Processing sketch [17] that draws ECG waves on the screen.

By starting the Processing program, data from the ECG sensor was obtained, which is shown in Fig. 8a. To compare the obtained results with the theoretical appearance of the ECG signal, Fig. 8b shows the ECG signal and its elements again.

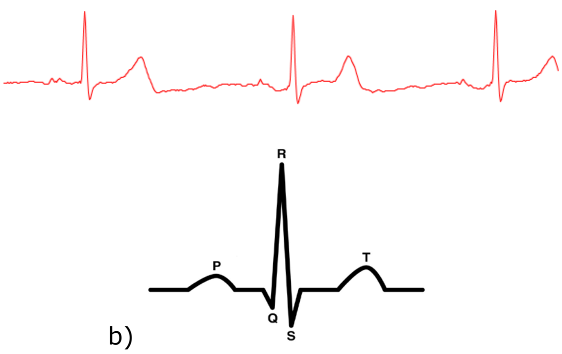

Figure 8. *a) The obtained ECG signal; b) The ECG signal elements*

By comparing the obtained result, one can notice the clear appearance of R and T peaks, as well as S valley, while the P peak is a little harder to see, but it is present. Based on the obtained results, the Q valley cannot be differentiated.

To show the effect of movement on the results, measurements were taken while the patient was moving. Those results are shown in Fig. 9.

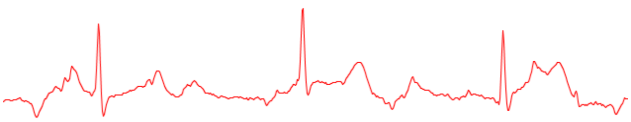

Figure 9. *The ECG signal while patients movement*

From Fig. 9, it can be noticed significant disturbances in the signal received from the sensor, which is mostly reflected in the instability of the P and T peaks.

If the places of the green and red electrodes are changed, an ECG result is obtained as in Fig. 10. It can be noticed that the peaks have become valleys and vice versa, therefore, an inverted ECG recording along the y-axis is obtained.

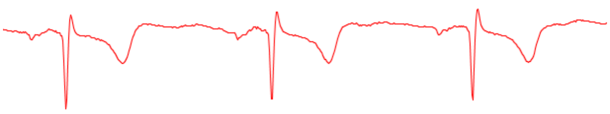

Figure 10. *ECG recording when replacing the green and red electrodes*

7. CONCLUSION

This paper describes a heart rate detection system based on an AD8232 ECG sensor and an Arduino Pro Mini microcontroller system. How the hardware elements of such a system are connected, as well as the software part that is used to detect the heartbeat and send data, is shown. In addition to the practical implementation of the realized system, a theoretical overview of the anatomy and physiology of the heart muscle, as well as all the details of the detection of its work, is given.

The implemented system is a single unit, but additional upgrades are possible. Since the connection is made on the connection board, it is possible to complete the system by making a printed circuit board with the possibility of further expansion.

It is possible to add a real-time clock to the system, to obtain precise time results for further data analysis. Also, it is possible to add an independent power source in the form of a battery and thereby be freed from being tied to a computer. Of course, the display of data itself could be realized on the connected LCD screen or the data could be sent wirelessly to a computer for processing.

It is also possible to add a place for an SD card, on which the data would be stored so that there would be no need to send them to the computer, i.e., offline data analysis could be performed.

As a possible wearable device, this sensor system can be followed with battery pack and some type of wireless communication. Preferable type would be Bluetooth Low Energy, and the power could be generated from bodily sources, by harvesting electrical potential of the human body.

On the software side, it is possible to implement an algorithm for pulse detection. Also, it would be interesting to implement some of the algorithms for the analysis of the QRS complex in real-time, so that preliminary analyzes of ECG signals could be performed, using wavelets or artificial neural networks [18 – 27].

This relatively simple system for ECG measurements can be an excellent exercise for biomedicine students. The biomedical engineers can learn the basics of human heart anatomy and electrical activity, while medicine students or professionals can analyze the given ECG measurement and provide the necessary incites.

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