System for EKG Monitoring

Solution based on Arduino microcontroller

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***Abstract*—In this paper the system for the electrocardiogram (EKG) monitoring based on the of Arduino microcontroller is presented. Detailed description of the electrocardiogram itself serves as a ground for building the proposed hardware and software solution. The software implementation is in a form of both, Mat-lab environment, and own application. Final output enables retrieval of the actual data in real time and further and provide the rudimentary diagnosis. Utilization of such device is for self-home diagnosis of arrhythmia.**

Keywords—Arduino; arrhythmia; C sharp; cardiovascular diseases; diagnosis; electrocardiogram; heart; Matlab

I. Introduction

Electrocardiogram machine got its popularity in the first half of the twentieth century. Examination at a cardiologist is considered these days to be nothing out of the ordinary. Despite the fact that EKG is only hundred years old, this technique is still the most reliable at determining an acute myocardial infarction (AMI). No other examination for diagnosis of such frequent and difficult problem as arrhythmia is being preferred. To make EKG machine work correctly, its proper construction and further configuration are necessary. Such device is used by people of different ages, for this reason, comfort, quick and exact usage should be provided. It is vital for the electrocardiogram to determine possible heart diseases in the shortest time possible.

The goal of this project is a construction of a machine analogous to the EKG machine and deployment of a software solution while still being able to achieve sufficient results. The brief introduction of EKG and hardware is introduced in the next sections with the subsequent rudimental implementation of both hardware and software.

II. Electrocardiogram in Detail

People have many things in common, and the electrocardiogram is one of those, providing no physiologic or pathologic factor is present. Labaš [1] describes it is a visual record representing the changes of electric potentials in the operation of cardiac muscle. The heart is a muscle in the body with special morphologic and functional role. Bada [2] refers to the myocardium as a syncytium of muscle cells is acting as a singular muscle fiber. During irritation – depolarization, which is gradually spread from atria to ventricles the potential differences originate, so-called action flows that create the electric field of the heart being spread by the surrounding structures of lungs and muscles. Due to the sensible registration machine, these flows are recordable also from body skin. Hampton presents in his book [3] dependency of the clinical diagnosis in particular on anamnesis and a lesser extent on a physical examination of the patient. EKG, as a tool, may support a diagnosis and in some cases is crucial for a concrete treatment of the patient. However, it is essential to perceive EKG as a tool and not as a goal itself. It helps with diagnosing the pain in the chest and also the proper utilization of thrombolysis is dependent on EKG. Further, it helps with cure of a heart attack or could contribute to a diagnosis of cardiac dyspnea. As a basis for the interpretation of EKG serves a recognition of the patterns based on several rules.

According to Pytliak [4] the electrical activity of the heart is visible by changes of electrical intensity also on the surface of the body. By sufficiently sensible galvanometer the changes on the surface of the body could be measured and registered, it is a principle of the creation of the EKG record. Summation of electric displays of all the cells in the given time interval results in a changes in the intensity.

III. Physiological Curve of EKG

Following Bada [2], the EKG curve is made by a group of positive and negative amplitudes so-called Wavelets. These are marked as given by international convention with letters [P,Q,R,S,T,U] just as were originally named by Einthoven. Horizontal passages of the curve are called intervals. Places between intervals are called segments. Physiologically, these passages of EKG are on the level of an isoelectric line. If the horizontal passages are above the level of the isoelectric line, it is the elevation, if the horizontal passages are under the level of the isoelectric line, it is the depression. Wavelets located above the level of the isoelectric line are called positive, and those under the level of the isoelectric line are called negative. Wavelets of which one part is positive and the second one negative are diphasic. Next, the relevant waves, intervals, and segments are described.

A. P wave

This wave is a sign of depolarization (contraction) of atrial muscle and also is the main criterion of the sinusoidal rhythm – when the initial impulse originated in the sinoatrial node and from there was carried to the atrial muscles.

B. Interval P-Q

From the beginning of the P wavelet to the beginning of the Q wavelet (if the wavelet Q is missing, then to the beginning of the wavelet R). This interval represents the time it takes for depolarization to spread over the muscle of the atria and the ventricles to the level of Purkinje fibers, this is referred to as a conversion time.

C. Q wave

This is the first negative wave after P wavelet or the first negative wave before the R wave. It is start of the ventricular complex and reflects the course of the depolarization of the interventricular barrier, which is of the whole ventricular muscle depolarized as the first one. Physiological Q wave tend to be just schematic, its absence is not pathological.

D. Q,R,S waves

Together they form the so-called initial ventricular complex of the same name, which reflects the depolarization of the ventricular muscle. It is bordered by the beginning of Q wave and ends with S wave.

E. S-T segment

This segment is the section from the end of the S-wave, where ends the ventricular QRS complex (J point) and the beginning of the T wave. Under physiological conditions, the S-T segment is on the level of the isoelectric line and reflects the early phase of repolarization of the ventricular muscle.

F. T wave

T wave has the same course as the ventricular complex, it is positive where the ventricular complex is positive. The T wave is a reflection of repolarization of the atrial muscles, thus it is always shown in the EKG. If the T wave is not present in the EKG, we say that it is on the level of the isoelectric line.

G. U wave

This wave is a non-constant part of the ECG curve, it tends to act as a small positive deflection behind wave. It is a reflection of so-called delayed repolarization of ventricular muscle. Lacking of U waves is never pathological. This wave is present in the EKG record from athletes.

H. Q-T interval

Interval, also known as electrical systole of heart, represents the time from the beginning of the ventricular QRS complex, i.e. from the beginning of the Q wave (in its absence from the beginning of the R wave) till the end of the T wave. It is a conclusion of depolarization and repolarization of the ventricular muscle. QT interval particularly depends on the heart rate.

IV. Arduino Microcontroller

Arduino is an open electronic platform [6], the principal reason of its success is user friendly hardware and software. Arduino is able to perceive the environment by utilizing various sensors and shields that may be connected to it. Arduino is a massive development kit based on the microprocessor ATMEGA328 and contains 13 digital input-output pins, 6 of them with support of pulse-width modulation (PWM) and 6 analog inputs [6]. Among all the free computer platforms for electronic projects such as Galileo or Raspberry was for this project chosen Arduino due to specific aspects, i.e. in conjunction with ECG it overruns other projects. Other aspects are: clearly and easily usable API with a simple programming language, then so-called Arduino shields that actually represent enhancements of the Arduino board [7]. Note that some of these shields are directly created for the purpose of human sensing signals. This very idea is the essential for our purpose, since it is possible to make own shield or to acquire already existing one. In our case, the shield provided by the Olimex is being utilized, bearing in mind the need to extract the highest possible signal quality. EKG shield can be connected in various ways, among the most basic are 12 - lead ECG.

V. Hardware Implementation

Based on the reviews of the available literature dealing with the EKG, and after comparative analysis of the options available to create an EKG device similar to a medical one, it was decided to utilize: Arduino UNO, shield Olimex EKG, electrodes designed for ECG shield. For signal processing is utilized Matlab environment and own software solution was also created.

As already stated, the project consists of two principal parts, i.e. hardware and software. In the hardware part, Arduino UNO with ECG Shield was combined. These two devices fit together very well. After their engagement in individual pins, Arduino was upgraded by the opportunity to capture the signals of the heart. Arduino was constantly connected to computer device and by this the need to use external battery was omitted, note that the energy was supplied through USB. It was proposed that that the EKG data is to be plotted directly on the screen using Matlab environment and our application. This condition removed necessity to use SD card for data recording, also use of mini displays or oscilloscope displays.

A. Electrodes

The original EKG devices used in medical practice in the art of cardiology use a combination of different electrodes. They combine electrodes connected to the legs, specifically to the ankles and wrists and electrodes that are attached directly to the chest near the heart. This project utilized electrodes from Olimex, which are also suitable for operation with Olimex shield. These electrodes are created exactly for connection in the form of Einthoven triangle. This type of connection includes three electrodes - one on the right hand, the second one on the left hand and the third one on the left leg. Three electrodes cross the notional heart. The right foot is taken as connection to the ground. Electrodes have also the option of renewable terminals. Terminals are affordable, thus a new set of terminals may be used for each tested person. The electrodes are connected directly to the ECG/EMG shield, specifically to the electrode jack.

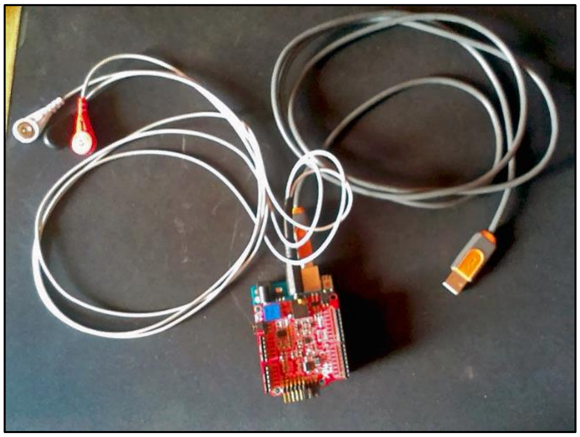

Fig. 1. Arduino, EKG shield and connected electrodes

Note that we can connect just one type of electrodes for a shield. Hardware component is depicted in the Fig. 1.

VI. Software Implementation

Software part utilized Matlab environment to output the direct sinusoid, specifically Matlab Data Acquisition Toolbox was used. Another approach included development of own secondary application, where the signals from the Arduino microcontroller were filtered and analyzed, note that application was developed in in C# language.

A. Matlab environemnt

In this case was created a simulation in which was simulated the RAW Arduino output via acquisition toolbox, which directly cooperates with the Arduino boards. In the simulation, specific COM port was selected to enable receiving of data and further is was opened. The entire simulation was portrayed in the cycle and a result was a graph. Graph itself was rather of chaotic nature, since we received input data from the RAW input along with noise.

B. Secondary application

The application can render down real-time ECG signal that can be filtered, also performs the calculation of the heart rate and enables detection of arrhythmia.

In the course of project, two programming languages for application development were considered, i.e. Java or C sharp. Both, Java and C Sharp, utilize RXTX libraries that can cooperate directly with Arduino boards. It was found that C sharp provides more advanced pre-build parts and principles that fit out needs. C sharp and Java in combination with Arduino facilitate us to connect Arduino to the USB port of the computer device and further its COM port can be found in the application. Once the COM port exists and is defined correctly, the application can send/receive messages from Arduino microcontroller. Communication takes place via the so-called serial interface. Main reason for utilization of C sharp was due to possibility of utilizing the advanced mathematical filters. These filters were in C sharp very well analyzed, and for this reason assisted in the implementation of the application in a significant way. The package OLIMEXINO-328 was used as well and helped in better synchronization with the shield.

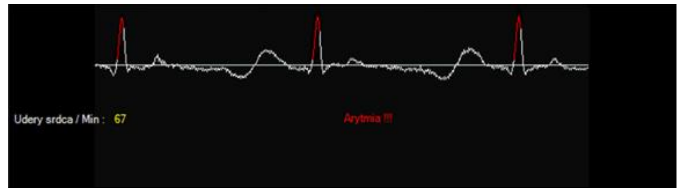

Fig. 2. Screen of application: Successful diagnosis

Screenshot of the secondary application is depicted in the Fig. 2.

Two types of filters were utilized:

1) Butterworth filter

Butterworth filter is a filter type for signal processing designed to provide the biggest possible flat frequency response. This is known as the maximum flat dimension filter. Originally it was described in 1930 by British engineer and physicist Stephen Butterworth.

2) Haar wavelet

Haar wave is a sequence recounting "square" functions, which form together a wavelet family or basis. Haar analysis is similar to Fourier analysis in allowing the target function in the interval to be expressed as an orthonormal function. The sequence of Haar was designed in 1909 by Alfred Haar.

C. Structure of secondary application

Application consists of eight main classes with basic Properties, References and app.configuration already included. Two of the principal classes are the classes of filters, one is for transformation, and the next one limits the size of the curves. Furthermore, there are classes for rendering down curves in real-time diagnostics, a class where the basic settings are and as the last one there is the main class.

Haar class creates a Haar wavelet filter. In this class there are three methods. First method is the one, which triggers a recursive method for calculating the Haar transform. The result of Haar transformation is a single integral number and a vector of coefficients. These coefficients are calculated from the highest to the lowest frequency however the Haar functions other way around, and therefore, we have a method which makes the inversion. The third method triggers the first two mentioned methods. Butter Worth is a class representing Butterworth filter. This class contains just one method, which takes information from the Fourier transformation of the class Fourier.cs. Consequently, a calculation to the original is in the progress. This method contains the conditions for the upper and lower limit of the filter. Fourier class contains an algorithm for calculation of fast Fourier transformation. Strop is class that sets scaling of the curve. The Class contains two methods. One method involves rendering down size of the curves. It also contains a condition for turning on and off scaling option. The second method runs in a cycle, and calls for the first one. Real Time is a class that contains a rendering of a curve in the real time. This class works with the package OLIMEXINO-328th. The main cycle can be found here, it receives information from the Arduino. Furthermore, there are cycles for applying Haar and Butterworth filters. In this class there are also saved settings for our filters along with scaling of the curve. There are also defined portrayals e.g. colors of lines and background, list of the heartbeat and the arrhythmia. Class called Diag deals directly with heartbeats and arrhythmia detection. Every single heartbeat can be detected and average heart rate calculated by the number of strokes per chosen time, which we calculate by the time between heartbeats and then convert it to a period of one minute. Arrhythmia is detected according to the time between heartbeats. If the time period is different between certain strokes, then it is evaluated as arrhythmia. Another class used was for communication with a serial port. This class concerns a method, which opens the COM port, which is from the beginning defined on COM.

D. Conclusion

The principal goal of this project was the construction and configuration the EKG-based device on Arduino microcontroller with an emphasis on its ease in controlling and applicability in routine practice, whether to professionals or the laymen. People are usually pretty familiar with EKG machine, which is used by cardiologists worldwide to determine different heart defects. Cardiovascular diseases take the top places in the list of the civilization diseases, one of the most common being the myocardial infarction (AMI). Such serious illnesses can be avoided by early diagnosis e.g. thanks to the devices such as EKG machine based on the Arduino.

The aforementioned sections introduced the advantage of this device being a quick diagnosing of cardiac arrhythmia. Generally, this examination is painless, and the patient has sufficient comfort and convenience. The greatest benefit would be for patients who need an immediate record of their health from the home. This benefit is the very consideration taken into account when developing such a device.

The disadvantages and related possible future improvements are the limited ability of the diagnosis since the exact type of arrhythmia cannot be determined. Next being the lack of storage of our measurement to a file or even lack of uploading it somewhere on the internet. However probably the biggest disadvantage of the current device is a large inaccuracy compared to the original EKG medical devices used in hospitals. These are the main concerns to be the principal focus in the future research.

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References

[1] P. Labaš, “Podklady na prijímacie skúšky z chémie”, Bratislava: ELÁN, 2013, 343 p.
[2] V. Bada, “Základy klinickej elektrokardiografie”, Bratislava: UK, 2010, 124 p.
[3] J.R. Hampton, “EKG stručně, jasně, přehledně”, Praha 7: Grada Publishing, a.s., 2013, 192 p.
[4] M. Pytliak, “Základy kardiografie pre štúdium ošetrovateľstva a ostatné zdravotnícke študijné programy”, Košice: Univerzita Pavla Jozefa Šafárika v Košiciach, 2009, 134 p.
[5] Arduino Uno [online] available at: http://arduino.cc/en/Main/arduinoBoardUno
[6] Co je to Arduino [online] available at: http://www.czechduino.cz/?co-je-to-arduino,29
[7] Vývojové prostredie a programovanie Arduina [online] available at: http://uart.cz/90/ide-a-programovani-arduina/