Electrocardiograph Design

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ABSTRACT

A portable electrocardiograph (ECG) monitor is necessary to monitor heart's health. In this paper, we introduce steps to build a basic yet efficient portable ECG device as well as its required software to display heart wave, heart rate and heart status. This device uses the positions of P, QRS, and T waves, and applies several detection algorithms to efficiently determine heart beat parameters so it can detect various type of arrhythmia diseases. The ECG successfully measures the heart rate, various heart shape intervals, and determine three types of arrhythmia diseases namely Bradycardia, Tachycardia, and Premature Ventricular Contraction. Extension function such as bluetooth compatible, LCD screen display, user interface menu and buttons are also included in the ECG device.

General Terms

Algorithms, Measurement, Design, Theory

Keywords

Electrocardiograph, ECG, Bradycardia, Tachycardia, and Premature Ventricular Contraction (PVC).

1. INTRODUCTION

Heart is the most important organs in human body, therefore monitoring and maintaining a healthy heart is crucial. As the heart cannot be seen, doctor use electrocardiography (ECG) to monitor its activity. However, it requires special tools and knowledge to extract and understand ECG. In order to simplify this complication, we propose a portable ECG device, which is able to display heart wave, heart rate and heart status, so everybody could check their heart at home.

2. ELECTROCARDIOGRAM (ECG)

2.1 Heart's Electrical System

The process of heart contraction starts with atria, which is the upper chambers of the heart, it then pumps blood to the ventricles - heart lower chamber. The ventricles will then pump blood to the all parts of human body. Heartbeat is created based on the electrical system that wires all the body electrical tissues.

The heart's electrical system contain a sinoatrial (SA) node, that will signal to the muscles heart. The signal will be send and link between the atria and ventricles. It then reaches atrioventricular (AV node), this acts as a pacemaker. The signal will continue passing through other heart tissues which results in the heart contraction.

2.2 ECG Signal

The ECG waveform consists of sequences of P, QRS and T waves. These threes waves form a shape of one heart beat (figure 1). The common most recognizable wave is the QRS complex, this is caused by depolarizing ventricular and repolarizing the atria. In addition, different types of segments can be measured relatively based on the position of these waves. Those will be use to determine various type of arrhythmia diseases.

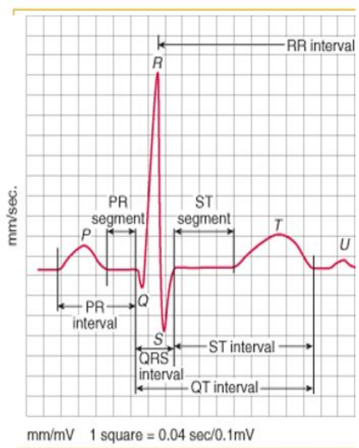

Figure 1: Heart beat waves

3. SYSTEM DESCRIPTION & THEORY OF OPERATION

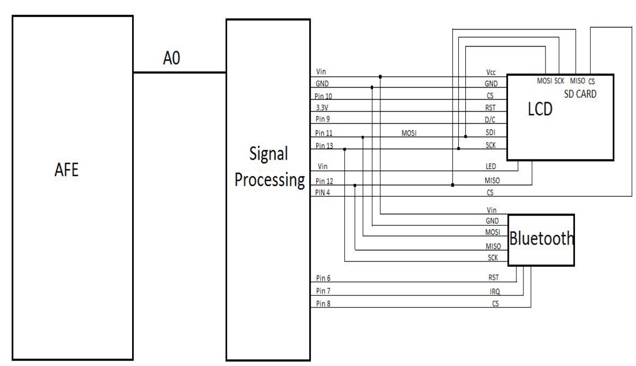

Figure 2: System block diagram

3.1 Hardware description

3.1.1 Analog front end

The figure below shows schematic to conduct ECG receiver. The value shown in the figure, however, is not the final value that we used to build our test device. The ECG hardware consists of a INA128 IC1, high pass filter(0.5Hz), Op-Amp MCP6004 IC2, low pass filter(150Hz), and a low resolution ACD.This device runs on 3.3V power supply.

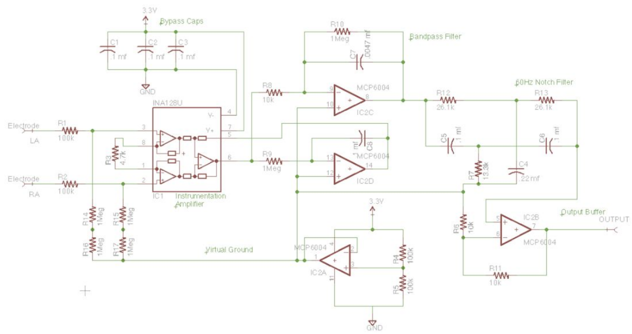

Figure 3: Schematic of AFE circuit

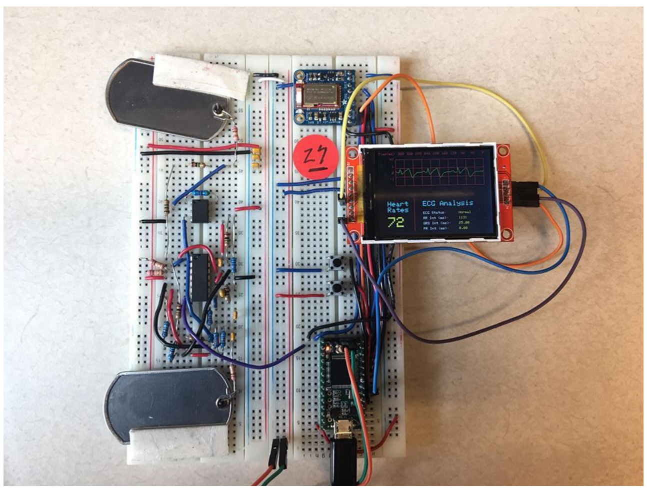

Figure 4: Overall hardware setup of ECG

This circuit is tested using oscilloscope with left hand on LA and right hand on RA.

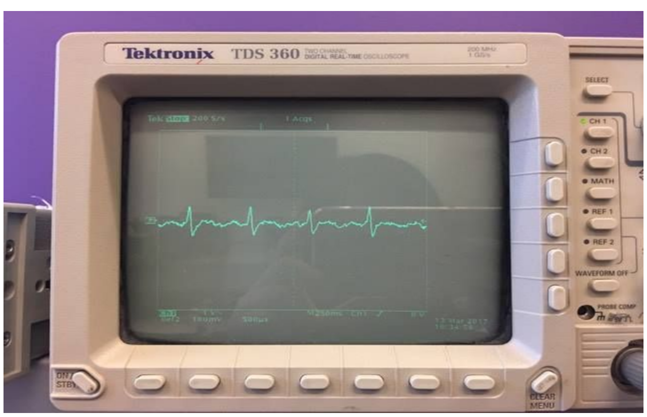

Figure 5: Oscilloscope display

3.1.2 Signal processing module

The core of processing tool is 32 bit Teensy 3.2 Development Board. It uses 72 MHz Cortex-M4 structure with 3.3V default voltage. Teensy has sufficient memory and processing power to implement filter algorithms and handle all the peripheral modules like LCD and bluetooth.

3.1.3 Display Module

The display module in this device is ILI9341 LCD. This module supports high resolution color graphics, which is important in illustrating the heartwave shape. On the screen, there are multiple information such as ECG, heart beat per minute, QRS time, PRI time and heart status.

Additionally, a SD card is attached to a display module so that the result of a heartbeat amplitude is saved as a text file. The result will also indicate the sample frequency, and has a name file, and EOF mark to determine the end of the text file.

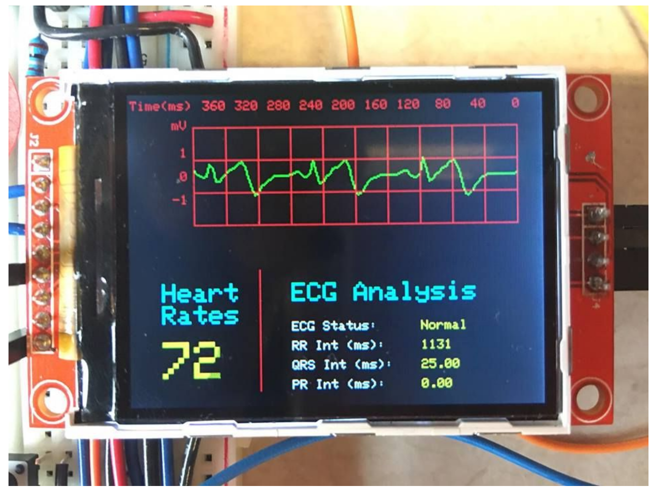

Figure 6: LCD interface of ECG

3.1.4 Bluetooth Module

The module used to communicate with mobile devices through bluetooth signal is Adafruit Bluetooth LE RF51. The shield provides a protocol to send out the heart rate on phone through an application named “nRF Toolbox.”

3.2 Theory of Operation

One crucial part of constructing the operation of the heart beat is the use of limb lead based on the idea of Einthoven. He was able to “capture the projection of the cardiac dipole in the frontal plane based on an equilateral triangle coordinate system” [1]. There will be three limb leads, two are on both arms, and the third is either left or right leg. Those are also the parameter of a function that projects a current dipole source to those three point of the body. One important factor is the lead polarity, if the lead is in reverse position, it will produce robust data, that is useless when applying analyzing signal technique.

The ECG signal works by collecting and amplifying the potential changes on the skin, which are caused by the electrical signal insides body and heart muscle to generate the heartbeat signal.. These potential changes are collected using ECG leads that are placed in various position of the body, typically left and high hands.. Each lead will look at the heart from different angles. The lead will sense the electrical activity of the heart muscles.

3.3 Theory of operation for ECG software, sample-rate and filter characteristics

3.3.1 Theory of operation

The AFE receives ECG analog signal from two dog tags and transfer it to signal processing module, Teensy board. This module then uses Analog - Digital Converter (ADC) to convert analog to digital signal. We implement an interrupt service routine using Programmable Delay Block (PDB) to trigger the ADB every 0.004 second. From here, the data are processed through low pass and high pass filters to remove all the potential noise from tense muscle or other possible sources. The output from filter will be displayed on the screen for heart wave visualization.

In order to detect the heart rate, the output signal has to be processed through differentiator and special square filter. The software set an adaptive threshold and an envelope filter to detect two replicate points from this result, two closest R peaks. The threshold will increase or decrease accordingly to the R peak amplitude of each different user heartbeat. The device records the time difference (in ms) between two points and calculate the heart rate (beat per minute, bpm) based on the function below:

Heart rate = 60000 / time difference

The result of detecting a R peak of a heartbeat will later use to implement the QRS algorithm.

3.3.2 Sample rate

The sample rate requirement for this project is 250 Hz (more than Nyquist rate to ensure there is no distortion as heart rate must be lower than 250/2 Hz).

3.3.3 Filter characteristic

The first filter that is used is 2nd order Butterworth low pass filter with 8 Hz cutoff frequency. This will filter all the large frequency data, which mostly act as noise in the ECG waveform:

y[n] = (1.329*x[n] - 0.694*y[n-2] + 1.588*y[n-1]

High pass butterworth filter with the cutoff frequency of 0.5 is applied to the signal to reduce the effect of baseline wander, or extragenoeous low-frequency high-bandwidth components.:

y[n] = (9.937e-1*x[n] + 0.9875*y[n-1]

The signal become more stable and the baseline wander effect was eliminated after passing it through the two filter.

3.3.4 Differentiator

In order to detect the R peak better, the filter signal is passed through again the differentiator filter. The purpose of this filter is to provide the instantaneous rate of change of the signal, since QRS complex is the most striking wave in a heartbeat, the outcome signal would have more clear and visible QRS slope.

A five points derivative transfer function is used for the differentiator filter:

$$H(z) = 0.1*(2 + z^{-1} - z^{-3} - 2z^{-4})$$

3.3.5 Squaring function

The result signal is squared by each point, this will help to enhance the effect of using a differentiator when detecting the QRS complex. However, we want to keep the sign of each point the same as what it is, so we multiply the function by its absolute value:

y[n] = x[n] * absolute(x[n])

3.3.6 Moving Average Filter

We also implement a moving average filter, using the equation below:

y[n] = (x[n - (N - 1) + x[n - (N - 2)] + … + x[n]) / N

Originally, this was use to act as a low pass filter, since both algorithms will apply similar effect that is to cut off the high frequency part of the input signal. However, the low pass filter function above produced a much more smoother effect. The moving average will later use to average the result of the heartbeat, the RR interval and QRS interval.

3.3.7 User Interface

A interface menu is implemented so that the user can choose between several options to use the ECG. The user can starts and stops the measuring process at anytime. The user can save multiple result of a heart rate for further analysis.

A thirty seconds auto stop is added to limit the time of measurement. Stabilizing algorithm also implemented so that it will only display the result when collecting enough data for other detecting algorithm.

3.4 Theory of operation for QRS detector

The QRS detector algorithm is implemented using the result when detecting R peak to calculate the heartbeat above. It is known that the average interval of a QRS complex is ranging between 0.06 - 0.1 second, or between 18 - 25 input data points since the ECG detect a new input date every 0.004 seconds.

The QRS complex is defined as a point where the signal starts to detect last baseline input (last positive input) after the P waves to the first input of a baseline interval. If looking from a R peak, the Q point is the second zero data from a R peak on the left, and S point is a second zero data on the right of a R peak. Keeping track of an index of the incoming data will help to determine the indexes of Q point and R point from a R peak index in a data array. The absolute value of a difference in the indexes or Q point and S point then is used to calculate the QRS interval.

3.5 Arrhythmia detectors implemented

The purpose of the ECG is using the shape of beat, a duration between each beat, as well as the distance between some heartbeat interval to determine any types of arrhythmia. Arrhythmia happens when a ECG detect an abnormal beats in any heartbeat parameters. Abnormal heartbeat is the reason for other type of illnesses such as changing blood pressure, stroke, or paralysis, etc. The reason of causing an abnormal heartbeat is when the electrical activities experience disturbances, which lead to the changing in heart rate and rhythm.

Using the result from a heart rate detector as well as an QRS complex detector, the device is capable of detecting three types of arrhythmias: Bradycardia, Tachycardia, and Premature Ventricular Contraction (PVC). The normal heart rate is ranging between 60-85 bpm.

3.5.1 *Bradycardia*

This type of arrhythmia happens when the heart rate is lower than 50 bpm. Due to a low rate, there will not be enough oxygen pump into the heart, which might lead to fainting, and also can lead up to death. If a heart rate is dropped lower to 50 bpm, Bradycardia is detected. The duration of heart intervals, shape or rhythm are similar to a normal heartbeat.

3.5.2 *Tachycardia*

The heart rate of this arrhythmia is when the heart rate is higher than 100 bpm. Due to the short period of time between each contraction is too short, it might lead to some several serious illnesses. The duration of heart intervals, shape or rhythm are similar to a normal heartbeat.

3.5.3 *Premature Ventricular Contraction (PVC)*

The PVC happens when first stage of heart contraction starts in the ventricles rather than in a atrial node. In this case, the QRS interval will be higher than 120 millisecond. The person who has PVC still have a normal heart rhythm, rates, and other similar heart intervals.

4. FUTURE WORK

Due to the time limitation of a project, not all the arrhythmia diseases are detected. In the next state of the project, the PR interval will also be measured to detect two additional type of heart diseases which are Premature Atrial Contraction (PAC) and Sleep Apnea.

In addition, the ECG is only capable of write in multiple result files in a SD card, but cannot retrieve the file and display the old heartbeat file. We will implement the algorithm so that the user will be able to open old heart rate files, display it on the LCD. The user should also be able to scroll between multiple files in the menu, and display them.

5. CONCLUSION

The algorithms for heart rate measurement, RR interval, and QRS interval are successfully implemented. The adaptive threshold for each different types of heart beat shapes is determined periodically. The low pass and high pass filter are used to sort out the noise and smooth the signal. The differentiator and special squaring function is used to emphasized the slope of a QRS complex. Moving average function is added to stabilize the measurement results of a heart rate, the heart shape intervals.

The ECG is capable of measuring the heart rate, RR interval, QRS interval and determine three types of arrhythmia diseases namely Bradycardia, Tachycardia, and Premature Ventricular Contraction. The real time heartbeat measurement is also displayed in the LCD screen. The final ECG machine has a menu interface so that the user can choose between different options using buttons.

6. REFERENCES

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