Cardiac Monitor with Mobile Application and Alert System

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***Abstract*– This research proposes a new approach on the Cardiac monitor by creating a portable Electrocardiogram (ECG) Cardiac monitor that will alert the user by detecting abnormal heart beats using a digital signal processing software. The alarm will be triggered when the patient experiences arrhythmias such as bradycardia and tachycardia. The equipment is simple, comfortable and small in size that fit in the hand. It can be used at any time and any moment by placing three leads to the person's chest which is connected to an electronic circuit. The ECG data will be transmitted via Bluetooth to the memory of a selected mobile phone using an application that will store the collected data for up to 24 hrs. The arrhythmia is identified by comparing the reference signals with the user's signal. The diagnostic results demonstrate that the Cardiac monitor alerts the user when an arrhythmia is detected through the Holter monitor and mobile application.**

Keywords—Cardiac Monitor, Heart disorders, Instrumentation Amplifier, Digital Signal Processing, Bluetooth, Mobile application.

I. Introduction

The beating heart produces an electrical signal that can be used as an analytic tool for observing some of the functions of the heart. The heart can be seen as a pump made up of muscle tissues. It requires a source of energy in order to function. The heart's pumping energy comes from an intrinsic electrical conduction system. An electrocardiogram (ECG) is the oldest tool used to record the electrical activity of the heart. This tool is still in use today. The ECG Cardiac monitor is a device that is continuously monitoring the cardiac electrical activity associated with signals recorded from the muscles and nerves of the heart for as long as the user needs. It requiring a simple task to change the battery and the SD card [1].

Each heartbeat is caused by a section of the heart generating an electrical signal which then conducts through specialized pathways to all parts of the heart. These electrical heart signals also get transmitted through the chest to the skin where they can be recorded by placing 3-leads [2].

The heart signal will pass by a conditioned signal that is going to manipulate an analog signal in such a way that meets the requirements for further processing. The signal will be converted to digital format in order to analyze the data to obtain useful information. By looking at the electrical patterns the Cardiac monitor can determine the possibility of congenital heart disease. There are many different types of abnormal heart beats [3][4]. The notion of this research is to design and build a low cost portable Cardiac monitor that diagnoses the patient and alert them when there is the presence of an arrhythmia such as tachycardia and bradycardia.

The cardiac monitor is able to work with weak signals ranging from 0.5mV to 5.0mV, combined with a dc component of up to 300mV (resulting from the electrode-skin contact), and a common mode component of 1.5 V (resulting from the potential between the electrodes and ground). The useful bandwidth signal ranges from 0.5Hz to 50Hz [5][6].

Additionally after obtaining the diagnostic result that is being displayed and stored it will be transmitted via Bluetooth to a mobile phone application. The Bluetooth technology replaced wire communication by exchanging the data over short distance consuming low power. By receiving the information via Bluetooth the mobile application will illustrate the heart trace in a certain period, give the beats per minutes and alert the user [7][8].

This is the first cardiac monitor of this kind that will impact the society by giving an alert and awareness to the person that his/her heart is having electrical changes and will provide time for immediate medical assistance in order to prevent any serious complication or even death.

The paper is organized as follows. Section 2 introduces the main components of the cardiac monitor with alert system and mobile application. Also, shows the experiments and results from a healthy 24 year old male subject. Section 3 contains the conclusions and suggestion for future work.

II. Procedure Description

A. Normal Waveform from an Electrocardiogram

Figure 1 shows two cycles of a normal ECG waveform.

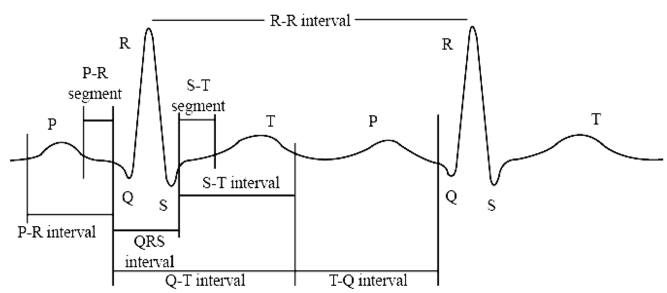

Fig. 1 Normal Electrocardiogram Waveform.

Low voltage fluctuation caused by the depolarization of the atria prior to contraction forms the P wave. The R-wave marks the ending of atria contraction and the beginning of ventricular contraction. T-wave marks the ending of ventricular contraction. The magnitude of the R-wave normally ranges from 0.1 mV to 1.5 mV. A narrow and high R-wave indicates a physically strong heart [4][5][6].

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The R-R interval measures the period of heart beat. Its inverse is the heart rate:

$$HR = \frac{60000}{R-R} \text{ (bpm)} \quad (1)$$

Where HR is the heart rate measured in beat-per-minute (bpm), R-R is the R-R interval measured in millisecond (ms). A changing R-R interval indicates irregular heart rate. The P-R interval is between the beginning of the P wave and the beginning of the QRS complex, the P-R interval represents the time between the beginning of the contraction of the atria and the beginning of the contraction of the ventricles. It normally ranges from 0.12 to 0.20 second. An abnormally prolonged P-R interval often indicates a special heart disease called "First Degree Heart Block". QRS complex is the largest amplitude portion of the ECG caused by the ventricular depolarization. Systole is referred the time during which ventricular contraction occurs. Atria re polarization occurs simultaneously, it is not seen due to the low amplitude of the signal generated by this process.

Next the ST segment connects the QRS complex and the T wave. It starts at the J point and ends at the beginning of the T wave. The ST segment represents the period when the ventricles are re polarized. QT interval is a measure of the time between the start of the Q wave and the end of the T wave in the heart's electrical cycle. A lengthened QT interval is a marker for the potential of ventricular tachyarrhythmia like torsade the pointes and a risk factor for sudden death. R-T interval represents the ventricular systole (muscle contraction) and the T-R interval represents the ventricular diastole (muscle relaxation).

B. *Electrodes*

The cardiac monitor uses three electrodes (3-lead) that are connected to form the Einthoven's triangle. The position of the 3-lead have two configurations: left hand (-), right hand (+), left leg (ground) and left lateral (-), right lateral (+), left hip (ground).

Each electrode obtains essential data from the ventricle and atrium that will help build the output signal. Electrode 2 signal is subtracted from Electrode 1 signal, both references to ground (Electrode 3) to be able to acquire a stable signal of a PQRST ECG waveform.

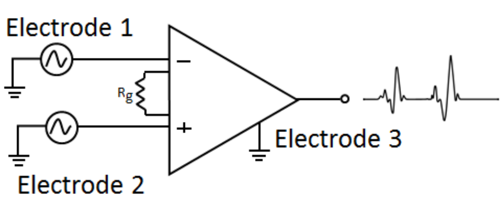

Fig. 2 Electrodes Schematic

The electrodes read the signal from the atrium and ventricular muscle. Figure 3 shows the combination of the SA, A and V that create the ECG waveform that helps gain the information needed to diagnose the patient.

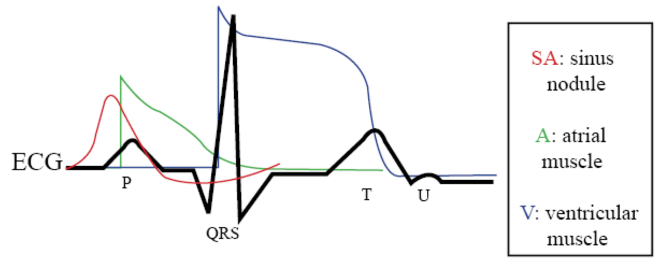

Fig. 3 ECG PQRST wave combination

C. *Electrocardiogram Design Components*

The block diagram (Figure 4) shows how the system and components are interconnected. It consists of three sensors (electrodes) that obtain the analog signal from the body fleeting it thru a signal conditioning that amplify and filter the signal in order to obtain the information necessary. The signal will be digitalized with a Teensy 3.1 that will activate the instructions required to diagnose the user. This diagnosis is represented as a numerical value that will be stored on a SD card and at the same time displayed at the LCD and sent via Bluetooth to the mobile application.

The human body signals range from 0.5mV to 5.0mV [2]. This signal passes thru the first stage of Signal Conditioning. The Signal Conditioning consists of an instrumentation amplifier AD622 114 that uses a 130 ohms resistor to amplify the voltage received from the sensors. The useful bandwidth signal ranges from 0.5Hz to 50Hz [3][4][5]. The second stage is a band pass filter that is composed of a high pass filter with a cut-off frequency of 0.53 Hz and a low pass filter rated at a cut off frequency of 10.53 Hz. The cut off frequency was calculated

$$f_L = f_H = \left(\frac{1}{2\pi RC}\right) \quad (2)$$

The final stage of the Signal Conditioning is the use of a LM 741 buffer amplifier that maintains the voltage level in order to avoid the attenuation of the signal. The Teensy 3.1 microcontroller rated at 72 MHz speed converts the analog signal to digital in order to manipulate the data and stores it in the SD card [6][7][8][9].

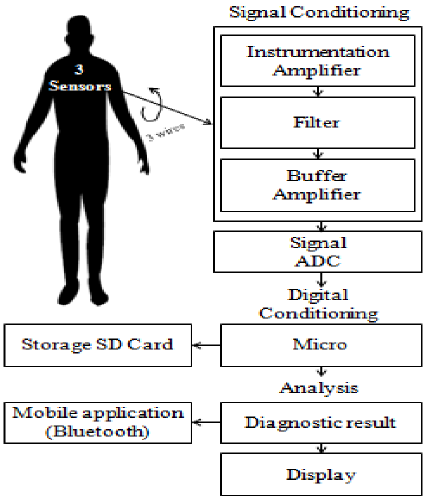

Fig. 4 Block diagram of the Cardiac monitor

In order to diagnose the user the program in the Teensy 3.1 detects the time interval between the R-peaks to be able to identify the period (T) and consecutively calculate the frequency (f) [3][4].

$$\Delta t = T = \text{time peak II} - \text{time peak I} \quad (3)$$

$$f \cong \frac{1}{T} = \textbf{frequency in Hz} \quad (4)$$

After obtaining the period and calculating the frequency the beats per minutes (BPM) is achieved multiplying the frequency by 60.

$$\text{BPM} = \text{frequency in Hz} * 60$$

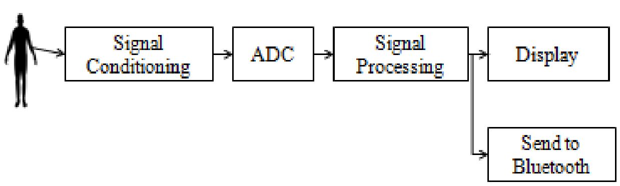

Fig. 5 Methodology

Having the information required the LCD 16*2 displays the BPM, the diagnostic result and alerts if the SD card is recording or full. 3.3 volts are used to power the SD card slot. The recording time will depend on the SD card memory size [10][11][12].

D. Digital Signal Processing Diagnose Software

The microcontroller receives the information through the analog pin (A0) this data is transfer thru a stored program in the Teensy's memory and at the same time a file named "ECG" is created to store the numerical data that represents the voltage variation of the heart rhythm. After receiving the signal the program will detect the first R-peaks stored as StartTime that will be subtracted by the second R-peak (TimePUm). Once the R-peaks are detected the calculation of period (T) and beats per minute (BPM) are executed. Just after obtaining the BPM the process will pass by three conditions Tachycardia, Bradycardia and Normal, each of these conditions have a range that will be compared to the data existent of the user.

This program will continuously display and calculate the BPM and the condition. Depending on the diagnosis if an arrhythmia such as bradycardia or tachycardia is detected a red LED will turn on. The SD card size will be constantly revised in order to display its status and close the file when a full memory is recognized.

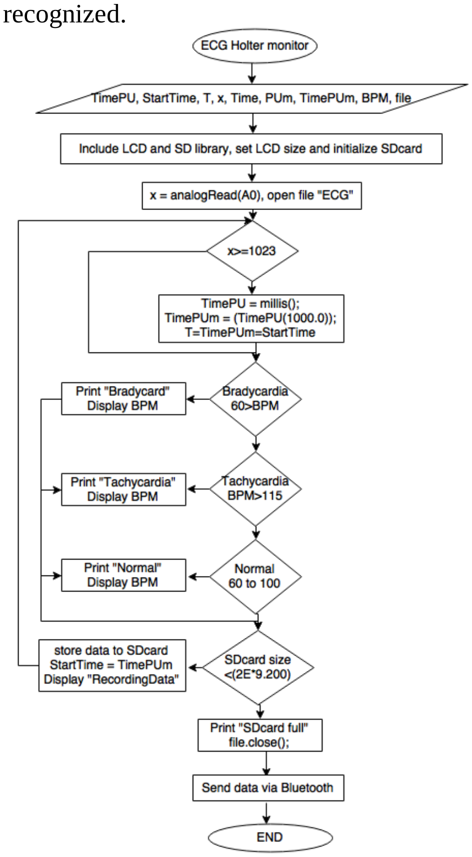

Fig.7 Flow Chart.

E. Mobile Application Classes

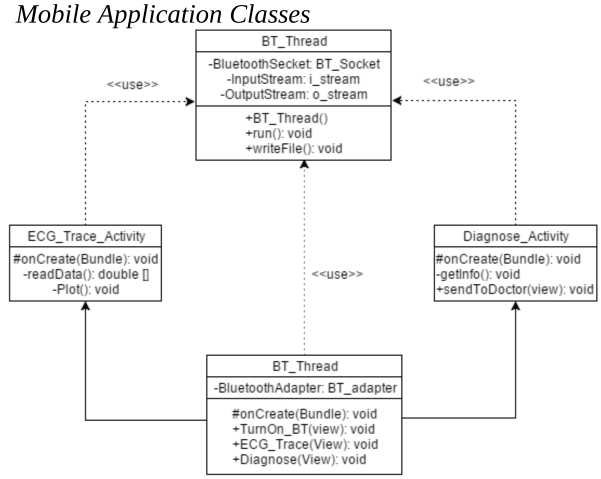

Fig. 8 Class diagram of the mobile application

The class diagram shows the three classes (one for each application's screen activity) and the thread in which the Bluetooth operations are being executed. The solid connectors mean that you can access each activity from one to the other. The segmented connectors mean that the thread is being executed in each one of those activities. The text in the top section of each block is the name of the class/thread; the middle section displays the global variables of the class in the format "Variable_Data_Type: Variable_Name"; the bottom section displays the constructors and methods of the class. The constructor is in the format "Class_Name()" and the methods are in the format "Method_Name(Parameter_Data_Type): Return_Data_Type". There is a symbol which represents the type of access of the element, it is establish for the symbol to appear in the left side, in the middle and bottom sections of each element. "-"means private, "+" means public and "#" means protected [15][16].

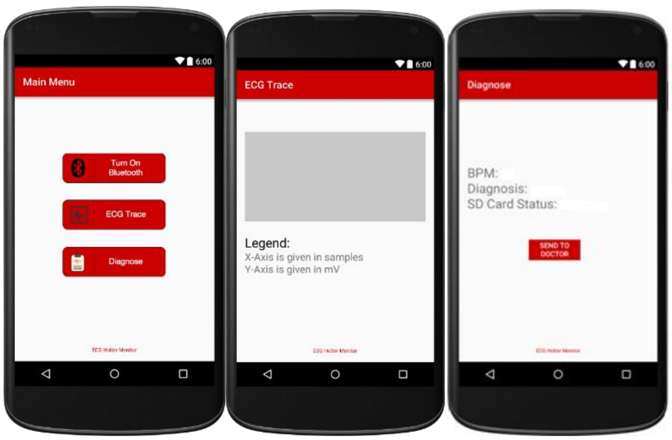

Fig. 9 ECG Holter Monitor application

F. *The Role of SD Card Storage*

One of the most important features of Cardiac monitor is that the LCD beside, display the heart beat per minute and the condition will also show when the device still recording and when it's capacity is full acknowledging the client to change the SD card.

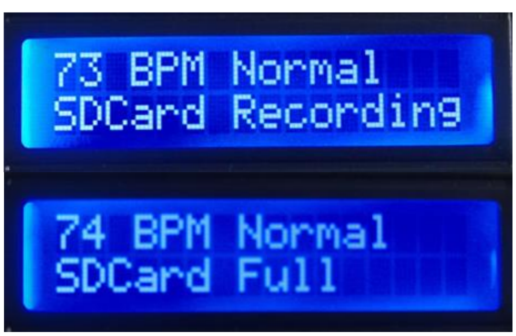

Fig. 10 LCD display

Once the SD card is placed on the computer it will automatically open a dialog box requesting to open a file. The file is selected demonstrating a new folder that was created named ECG. This folder contains all the heart beats in numerical numbers [12][13][14].

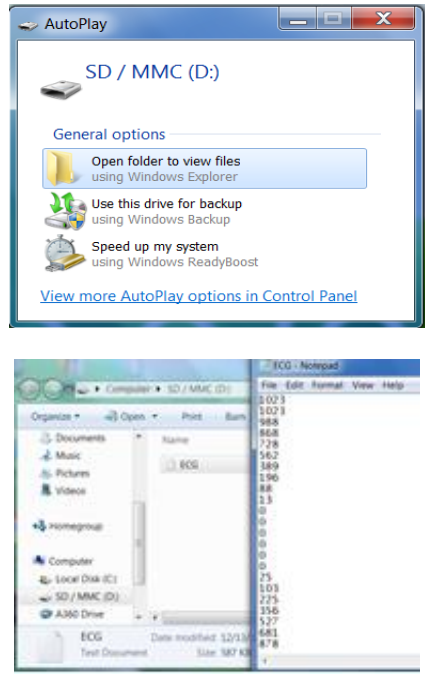

Fig. 11 SD card ECG folder

G. *Power Source*

The Cardiac monitor is powered by a nominal supply of 9 volts. These 9 volts were regulated to 5 volts to supply power to the microcontroller, SD card slot and LCD 16*2.

III. Results

The Cardiac monitor was tested on a 24 year old male. Figure 13 shows the connection of the electrodes with the body in order to obtain the electric signals of the heart. As seen in the same figure, the cardiac monitor displayed.

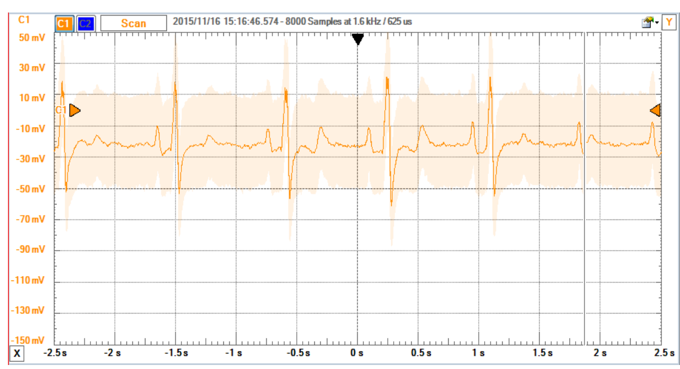

Fig. 12 24 year old male samples.

a normal diagnosis when the subject heart rate was between 60 and 100 bpm and a tachycardia when the heart rate was over

100. As soon as the devise detected an abnormal heart rate a red LED turns on to alert the user [7][8][9][16].

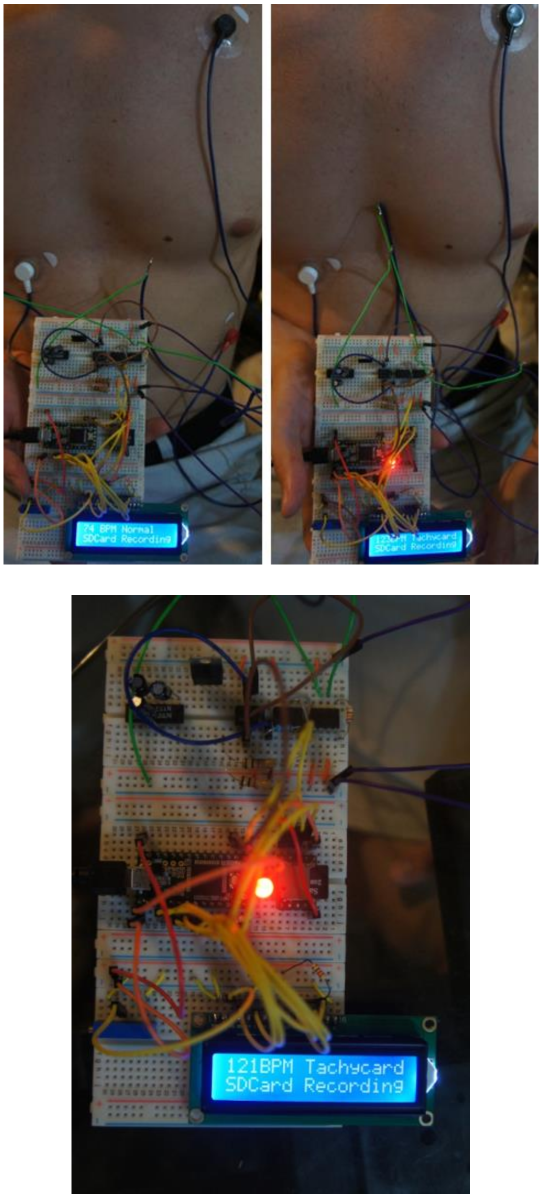

Fig. 13 Placement of ECG Holter monitor on the client and diagnosis

By pairing the Bluetooth module to a Smartphone and running the application, we were able to display the diagnosis as well as the trace of the heart in real time. Storage of data through an SD card allowed us to easily view or maintain data that could later be used personally or by doctors.

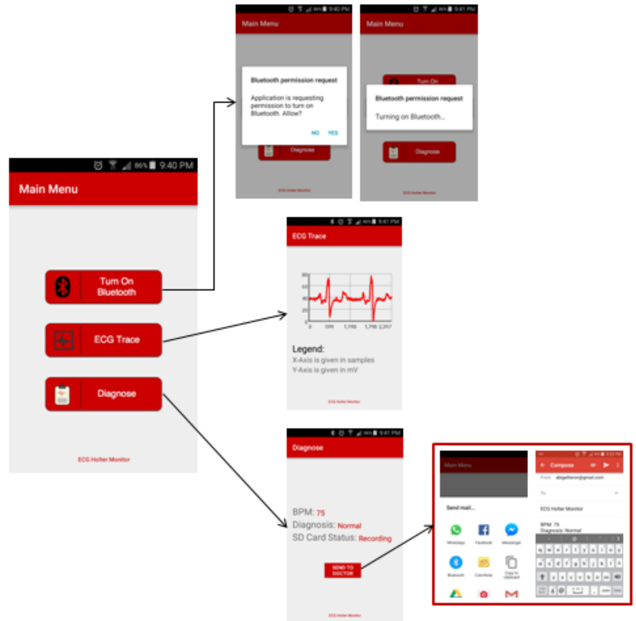

Fig. 14 Interaction of the Mobile application

To make the Cardiac monitor as compact and comfortable as possible, the size of the circuit was reduced. The best way of reducing the size of the circuit was creating a printed circuit board (PCB) that connects components using conductive tracks on copper sheets laminate. The prototype for the PCB is a multi-layer (3 layer) design created on AutoCAD. The size of the PCB ended being 10 x 8.5 mm.

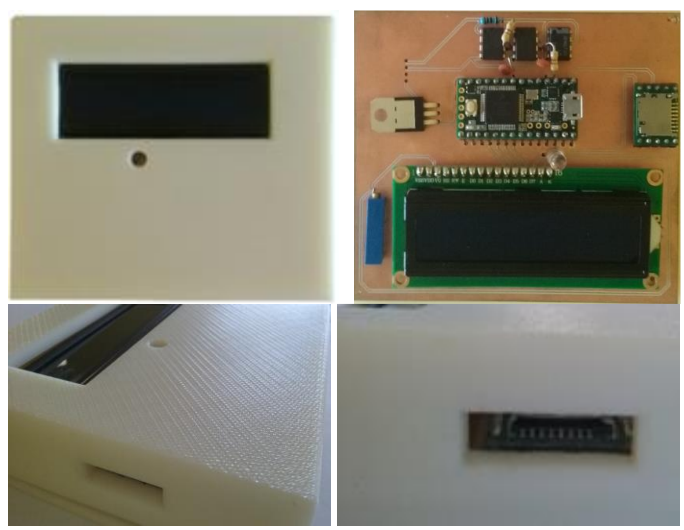

Fig. 15 Final result of the ECG Holter monitor with alert system and mobile application

Figure 15 shows the final result of the Cardiac monitor, the case to cover the PCB was created on an acrylic thread 3D printer. The final size of the Holter monitor shown on Figure 15 is 11 x 9.5 mm and contains four holes, for the LCD, LED, SD card porter and the electrodes cable.

IV. Conclusions

A cardiac monitor was developed to operate as the ones used by doctors and surpass them by adding new features. By continuously calculating the time and frequency between the hearts R peak, a real time diagnosis of the user heart beat is obtained. Heart beats below 60 per minute result in a bradycardia, and above 100 the user will be diagnosed with a tachycardia. In addition to the Cardiac monitor displaying the condition of the heart, the user can observe the trace of his heart in real time using the mobile app created for Smartphone's. Data is stores in an SD card that can be easily removed and changed to accommodate to the users need. Ones the storage capacity of the SD card is reached the LCD display will change from recording to SD card full. By using the Smartphone app, many features like the heart trace can be implemented, thus increasing the functionality of the ECG Holter monitor and reducing its size.

By using the needed elements as well as the smallest ones possible we were able to create an economical, comfortable, and portable device that can be used by any person in need. Eventually many more improvements to the code will be made to add new features as well as making the device smaller.

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