# PORTABLE NON-INVASIVE CARDIAC HEALTH MONITORING DEVICE

**A Thesis Submitted to the Department of Electrical and Electronic Engineering of BRAC University**

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# DECLARATION

We hereby declare that this thesis is based on the results found by ourselves. Materials of work found by other researchers are mentioned by reference. This report is a record of the thesis titled “Portable Non-invasive Cardiac health monitoring device”, submitted to the Department of Electrical and Electronic Engineering of BRAC University by the students whose names are given bellow in partial fulfillment of the requirements of the degree of Bachelor of Science in Electrical and Electronics Engineering in BRAC University.

Date: 20.08.2017

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# Abstract

Recent technological advancements have accelerated public healthcare sector by developing biomedical devices with advanced functionalities. New innovations have made it possible for the consumers to use portable devices which are capable of acquiring vital signs of human body with excellent accuracies. Handheld user-friendly ECG devices are being produced for consumers to monitor their cardiac health. Preventive measures can be taken by monitoring the heart condition frequently and periodically. Considering the fact that a significant portion of the population is suffering from cardiovascular diseases the importance of a low cost, compact and reliable heart-monitoring device is crucial. We are proposing a low cost biomedical device that can non-invasively measure ECG, $SpO_2$, PPG, body temperature and heart rate variability (Poincare plot). This device is capable of acquiring the electrical activities of the heart and digitally plotted which can later be interpreted by professionals to check physical anomalies. SpO2 measures the percentage of oxygenated hemoglobin in blood and detects the efficiency of the lung. PPG signal provides information about condition of the arteries and the temperature sensor shows body temperature from fingers. These sensor data can be accessible both from the computer and on smartphones via Bluetooth. Interpretation and analysis of the different signals gathered and correlation present in them can alleviate difficulties in early diagnosis of vital symptoms.

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# Chapter 1

# Introduction

## 1.1 Objective

ECG is most widely used tool for detection and diagnosis of broad range of cardiac conditions. This technique has successfully contributed in understanding and treatment of every cardiovascular disease. The oxygen saturation provides the lung efficiency information and the PPG signals provide information about the condition of the arteries. The objective of this project is to design a cardiac health monitoring system that is affordable for everyone and capable of measuring these bio signals with good accuracy.

## 1.2 Motivation

Portable health monitoring devices are available in developed countries for consumers to monitor their health condition at home. But these devices are not affordable for countries like Bangladesh where cardiovascular diseases take up to 17% of the total mortality rate. [1] Sometimes it is difficult for people in the rural areas to travel to the nearest hospital to take these tests. As it is not affordable for most of them to take regular tests. The annual morality rate per 100,000 people from cardiovascular diseases in Bangladesh has been raised by 128.9% since 1990, which amounts to an average of 5.6% per year. [2] According to International Bureau for Epilepsy almost 1.5 to 2.0 million people in Bangladesh are suffering from epilepsy. [21]

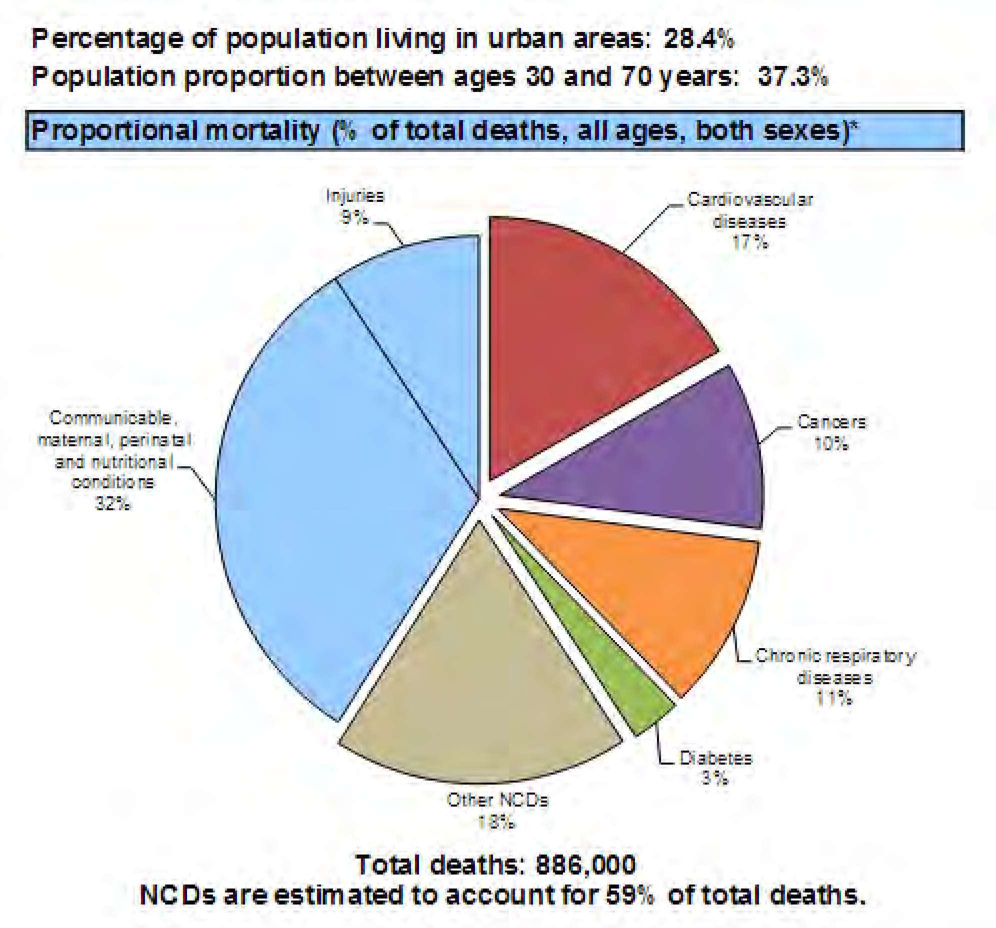

Figure: Pie chart for mortality rate in Bangladesh

Continuous monitoring of ECG, HR, SpO2 and HRV can predict vital signs of health risks. Heart Rate Variability (HRV) can even predict the epileptic seizures in advance. [20] As mentioned earlier a huge proportion of people in Bangladesh are already suffering from cardiovascular diseases or are at risk, low cost devices like those should be made available to the mass people. The necessity of this type of device has motivated us to make this device.

## 1.3 Literature Review

### 1.3.1 Electrocardiogram (ECG)

Electrocardiography (ECG or EKG) is a very commonly performed cardiology test. ECG is the procedure of recording the electrical activity of the heart over a period of time by placing electrodes on the skin. The electrodes placed on the skin can detect the small electrical changes on the skin that occur due to the heart muscle's electrophysiologic sequence of depolarizing and repolarizing during each heartbeat. The heart pumps blood when the muscle cells make the heart wall contract. This contraction process initiated by the muscle cells generate their action potential and creates an electrical current. This current spreads all over the body and creates potential differences between various parts of the body. The waveform produced by these bio-potentials is known as the ECG. The ECG waveform can be recorded/detected using surface electrodes placed on the patient's limbs and on the surface of the chest. The overall magnitude of the heart's electrical potential is then measured by placing the electrodes in 12 different angles (leads). Hence, the overall magnitude and direction of the heart's electrical depolarization is acquired throughout the cardiac cycle. [3] The voltage versus time graph produced by this non-invasive bio-potential detection procedure is termed as an electrocardiogram. Interpretation and analysis of the various waves of the electrocardiogram provides important information and leads to diagnosis of cardiovascular diseases. An ECG can be used to measure the rate and rhythm of heartbeats. Doctors can also detect the size and position of the heart chambers, damaged heart muscle cells or conduction system, the response of cardiac drugs, and the behavior of the artificial pacemakers. [4]

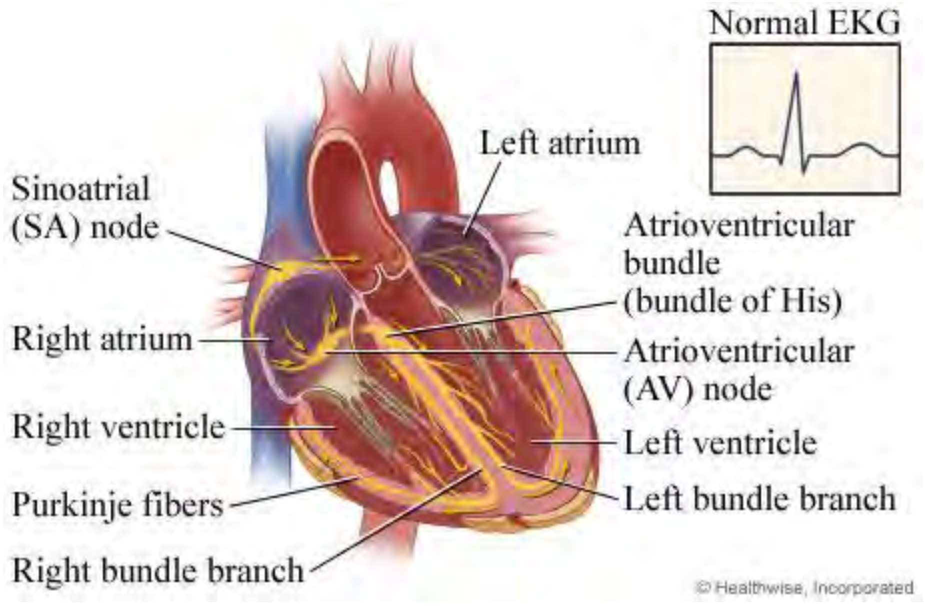

Figure: The hearts electrical system.

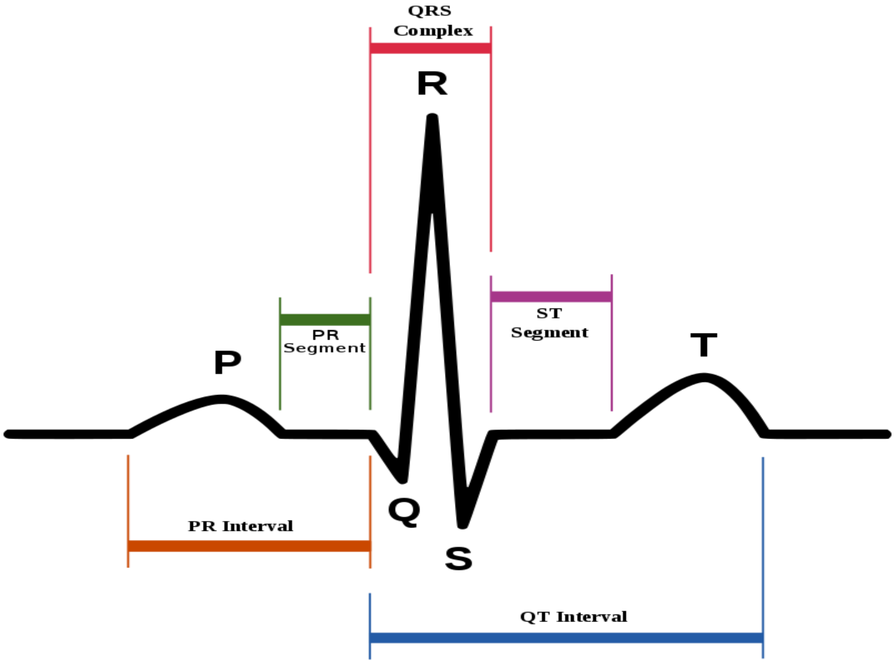

Figure: The basic ECG wave.

#### 1.3.1.1 P wave

In the normal heart, each beat begins with the discharge (depolarization) of the sinoatrial (SA) node, high up in the right atrium. This spontaneous event usually occurs 60-100 times per minute. The first distinguishable wave is visible when the impulse spreads from the SA node to depolarize the atria. This is how the P wave is produced. The duration of P wave is less than 0.08s.

#### 1.3.1.2 PR Interval

The time it takes for the depolarization wave to pass from its origin in the SA node, across the atria, and through the AV node into ventricular muscle is called the PR interval. This is measured from the starting point of the P wave to the starting point of the R wave. The duration of the PR interval ranges between 0.12 to 0.2s.

#### 1.3.1.3 QRS Complex

The QRS complex signifies the expeditious depolarization of the right and left ventricles. As the ventricles have a large muscle mass than the atria, the QRS complex commonly has a much higher amplitude than the P-wave. The duration of the whole QRS complex is 0.08 to 0.1s.

#### 1.3.1.4 ST segment

ST segment represents the period when the ventricles are depolarized. No more electrical current can be passed through the myocardium in this transient period. It starts from the end of the S wave to the starting point of the T wave.

#### 1.3.1.5 T wave

Repolarization (recharging) of the ventricular myocardium to its resting electrical state is called T wave. The duration of a T wave is 0.16s.

#### 1.3.1.6 QT Interval

The time required for the ventricles to activate and readjust to the normal resting state is called the QT interval. It is measured from the starting point of the QRS complex to the end of the T wave. The duration of a QT interval is less than 0.44s.

#### 1.3.1.7 U wave

Although the origin of the U wave is unresolved, it may represent repolarization of the interventricular septum or slow repolarization of the ventricles. [6]

### 1.3.2 Photoplethysmogram (PPG)

Photoplethysmography (PPG) is a non-invasive optical technique for monitoring heart rate and Heart Rate Variability (HRV). It uses Light Photo Sensor (LPS) to capture light reflectance intensity on the finger. Light is emitted to the examined tissue, where it is scattered and absorbed. The transmitted or back-scattered light intensity changes from the tissue can be detected by using photo-diode. The signal is sampled, filtered, processed and sent through an amplifier. Traditionally the heart rate variability (HRV) of a patient is measured at the hospitals using the ECG electrodes which are placed on the patients' chest.

From the ECG waveform, the R-R interval (inter-beat interval) can be obtained to extract the HRV information. There are other methods of extracting HRV information but Photoplethysmography (PPG) is the simplest one. [7]

#### 1.3.2.1 Heart Rate

The heart rate actually means the ventricular rate, which is associated with the patient's pulse. QRS complex on the ECG is produced by the depolarization of the ventricles. So the rate of QRS complexes are measured to determine the heart rate.

Bradycardia is usually defined as a heart rate below 60 beats/min. It is used to identify the cardiac rhythm and conduction disturbances. Common problems among bradycardiac patients that require considerations are sinus bradycardia, sick sinus syndrome, second-degree and third-degree atrioventricular (AV) block, 'escape' rhythms, AV junctional escape rhythm, ventricular escape rhythms, asystole.

Tachycardia is usually defined as a heart rate above 100 beats/min. Identification of cardiac rhythm is required for the patients with tachycardia. [8]

#### 1.3.2.2 Heart Rate Variability (HRV)

The physiological phenomenon of deviation in the time interval between heartbeats is called Heart Rate Variability (HRV). The interval between beats are measured for the determination of HRV. A reduction in HRV sometimes caused by different cardiovascular diseases like myocardial infraction, cardiac transplantation, myocardial dysfunction or even sudden cardiac death. Before calculating HRV using (2) time on each peak are stored to find differences between them. HRV for each individual are different and there are many formulas to calculate maximum HRV for different categories, however, for standard users, Karvonen formula (3) still can be used to determine maximum HRV based on age. where Ti is time interval between peak to peak in the second, tb is time at current peak and tb-1 is time at previous peak. [18]

$$T_i = t_b - t_{b-1} \qquad (1)$$

$$HRV = T_i \; x \; 60 \qquad (2)$$

$$HRV_{max} = 220 - Age \qquad (3)$$

#### 1.3.2.3 Poincare plot

A Poincare Plot is a geometric representation of a time series (n1, n2, n3, n4....nX). It graphs the current data point compared to the previous data point in a cartesian coordinate system. In Poincare plotting, the x-axis is labeled 'n' and represents the most recent, or current data, and the y-axis is labeled 'n-1', which represents the previous value which came just before n. A point cloud is plotted which reveals the symmetry of inter-beat interval (IBI) values over time. [9]

#### 1.3.2.4 HRV Time Domain

In time domain HRV, the inter-beat interval (IBI) is shown in respect to time. The change in IBI due to the change in breathing pattern is also visible in this graph. [10]

#### 1.3.2.5 HRV Frequency Domain

Waveform of the Time Domain moves up and down as it slowly progresses forward with each one of the heartbeats. The frequency contained in this time changes too. Each time the wave changes direction that constitutes 1/2 of a wave. The half wave is used for approximation of HRV in frequency domain. [11]

### 1.3.3 SpO2

MAX30105 is used in this project as a peripheral capillary oxygen saturation (SpO2) detection sensor. SaO2 is the blood-oxygen saturation reading that indicated the percentage of hemoglobin molecules that are saturated with oxygen in the arterial blood. The determination of SaO2 from pulse oximetry is known as SpO2.

#### 1.3.3.1 Absorption of light in the blood stream

Pulse oximetry is a process where light emitting diodes radiate red and infrared light, which penetrates the skin cells and tissue. Emitted light from the sensor is mostly absorbed by the tissue, blood and bone, the remainder of the light is reflected back to the receiver end of the sensor. The sensor is usually attached to extremities like the finger, toe or ear where the arterial blood is closer to the skin. This reduces the amount of light absorbed by the tissues and get a better reading from the sensor. To isolate the amount of light absorbed in the blood, the sensor only takes the reading where the absorption amount changes in short intervals. This is due to the pulsation of the arteries as the blood is pumped from the heart. The absorption rate at different molecular constitution is shown in Figure 1.5.1.

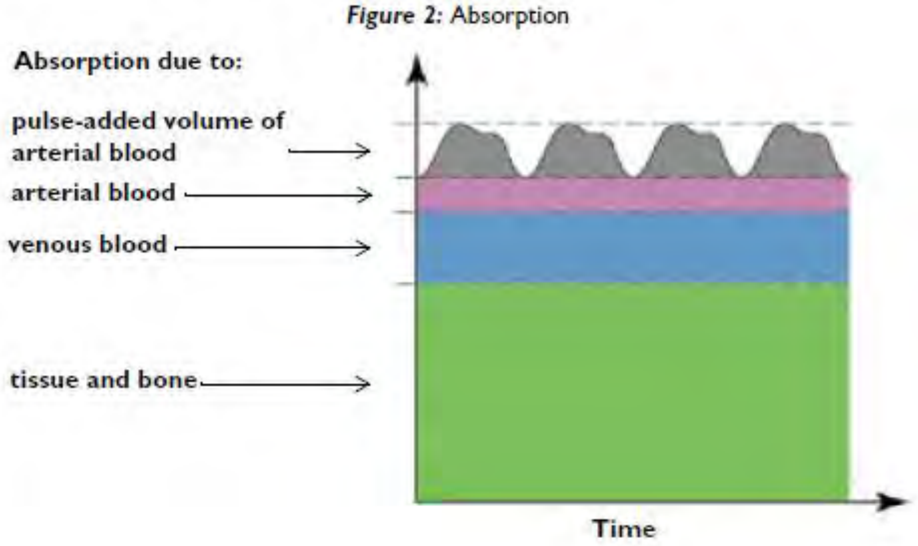

Figure: Absorption at different molecular constitution.

Amount of light reflected back into the sensor indicated the saturation of oxygen bound to the hemoglobin in the blood. In the spectrum of emitted light, most of the infrared light is absorbed by the oxygenated hemoglobin (oxyhemoglobin or HbO2) compared to the red light, while the deoxygenated hemoglobin (Hb) absorbs more red light compared to infrared light. [12]

### 1.3.3.2 Oxyhemoglobin Dissociation Curve

SpO2 can determined using oxygen partial pressure (PaO2). PaO2 is related to SpO2 through the Oxyhemoglobin Dissociation Curve shown in Figure 1.5.2. Very high SpO2 levels can cause the PaO2 values to vary extensively. Therefore SpO2 cannot be used to warn of high levels of PaO2.

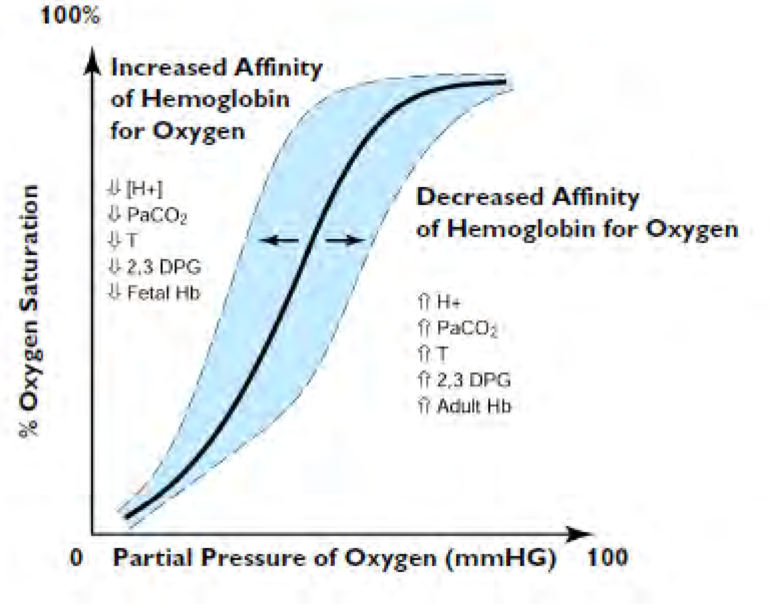

Figure: Oxyhemoglobin Dissociation Curve

### 1.3.3.3 Medical Significance

SpO2 has a lot of medical significance in the diagnosis of diseases. For a healthy person at sea level, the SpO2 percentage can vary from 96% to 99% and should be above 94% to be considered healthy. At 1600 meters oxygen saturation should be above 92%. If the percentage falls below 90% it can lead to hypoxia, a medical condition which deprives the body or a part of the body of oxygen.

### 1.3.4 Temperature Sensing

Human body temperature varies according to age, exertion, infection, sex, time of day, reproductive status of the subject, the place in body at which the measurement is made the subject's state of consciousness, and emotional state. Usually the body temperature of a normal human ranges from 36.5-37.5 °C (97.7-99.5 °F)[24]. There are many medical conditions where the body temperature deviates from the normal range. Hypothermia is when the body temperature falls below 35 °C (95.0 °F)[23], it can be diagnosed as fever or hyperthermia if the temperature rises above 37.5 or 38.3 °C (99.5 or 100.9 °F)[25][26], and finally if the temperature is above 40.0 or 41.0 °C (104.0 or 105.8 °F) it is considered as hyperpyrexia.[25][26]

# Chapter 2

# Hardware Components

## 2.1 Components Used

2.1.1 Arduino Mega 2560

2.1.2 AD8232 ECG sensor

2.1.3 ECG electrode cable

2.1.4. Self-adhesive electrode pads

2.1.5 Sparkfun Pulse sensor

2.1.6 Sparkfun MAX30105

2.1.7 Bluetooth HC-05 module

### 2.1.1 Arduino Mega 2560

Arduino mega 2560 is a microcontroller based board powered by the ATmega1280 chip. It acts as the controller for all the sensor, where the coder defines the functions that need to be performed at certain pins during certain periods of time. The microcontroller can read data from the sensors and present them to the coder, it can also give instructions to sensors to perform certain actions. Arduino Mega utilizes 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Arduino Mega can be powered with an external power supply or a USB connection. External power (non-USB) can be provided through AC-to-DC adapter or battery. The board can operate at an external power supply ranging from 6 to 20 volts. If the voltage is less than 7 volts however the 5V pins may not provide adequate output and may be unstable. If the voltage crosses over 12V the voltage regulator may overheat and damage the board. Therefore the recommended voltage is 7 to 12 volts. ATmega1280 contains a 128 KB of flash memory for storing codes (of which 4 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM. The complete characteristics of Arduino Mega are shown in the Table.

| | |
|---|---|
| Microcontroller | ATmega1280 |
| Operating Voltage | 5V |
| Input Voltage (recommended) | 7-12V |
| Input Voltage (limits) | 6-20V |
| Digital I/O Pins | 54 (of which 15 provide PWM output) |
| Analog Input Pins | 16 |
| DC Current per I/O Pin | 40 mA |
| DC Current for 3.3V Pin | 50 mA |
| Flash Memory | 128 KB of which 4 KB used by bootloader |
| SRAM | 8 KB |
| EEPROM | 4 KB |
| Clock Speed | 16 MHz |

Table: Characteristics of Arduino Mega 2560

Figure: Arduino Mega 2560

### 2.1.2 AD8232 ECG sensor

The AD8232 is an integrated sensor for signal conditioning of cardiac bio-potentials for heart rate monitoring. It has a group of specialized instrumentation amplifier (IA), an operational amplifier (A1), a right leg drive amplifier (A2), and a midsupply reference buffer (A3). In addition, the AD8232 includes leads off detection circuitry and an automatic fast restore circuit that brings back the signal shortly after leads are reconnected. The AD8232 contains a specialized instrumentation amplifier that amplifies the ECG signal while rejecting the electrode half-cell potential on the same stage. This is done with the help of an indirect current feedback architecture. This architecture reduces size and power compared with other chips. [14]

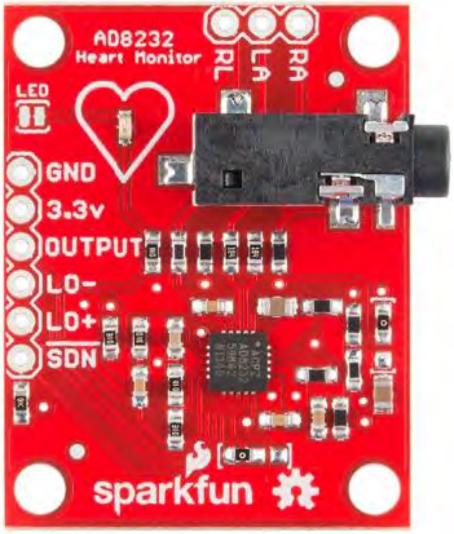

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Figure: Sparkfun AD8232 ECG sensor

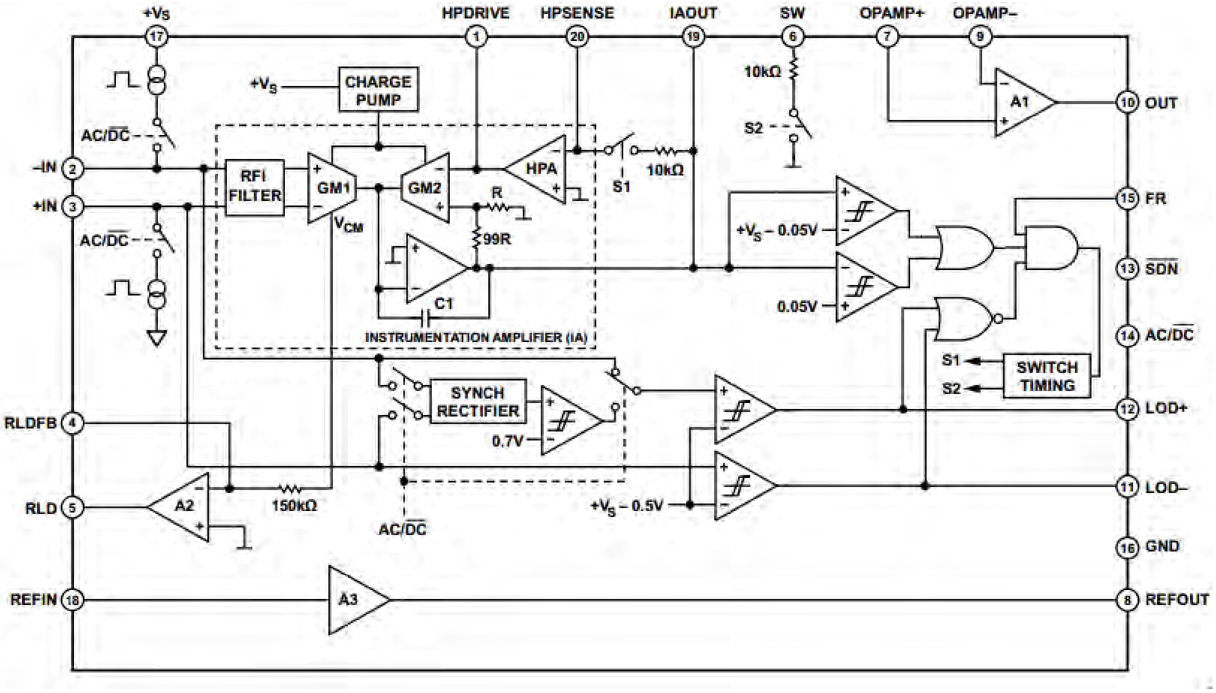
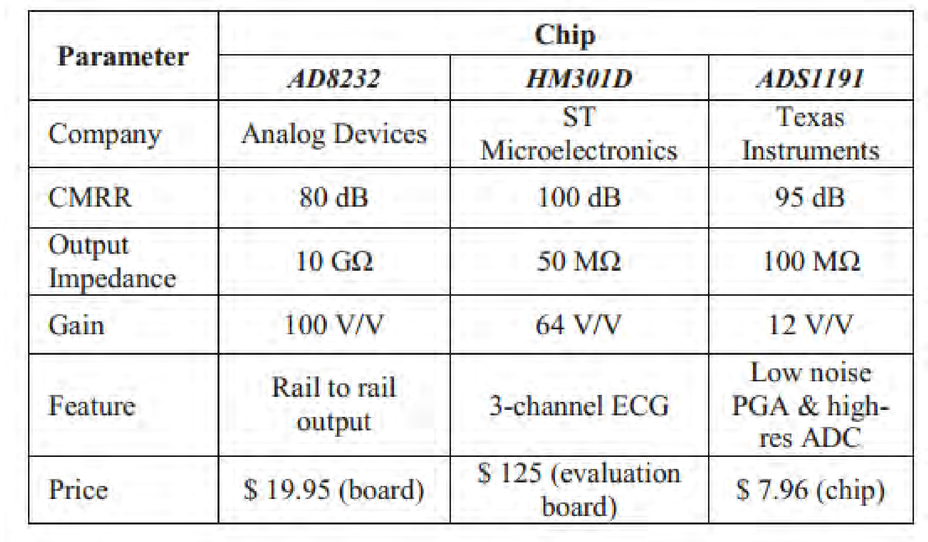


Figure: Simplified schematic diagram of AD8232

AD8232 is preferred over other chips because it has the best output impedance and gain. HM301D is three channel, which is not required as we are working on a single channel ECG. ADS1191 does not provide high enough gain and lacks good resolution. For highpass filter, two-pole HPF is used and for lowpass filter, two-pole Sallen-Key LPF is used. [17]



| **Parameter** | **Chip** | | |
|---|---|---|---|
| | ***AD8232*** | ***HM301D*** | ***ADS1191*** |
| Company | Analog Devices | ST Microelectronics | Texas Instruments |
| CMRR | 80 dB | 100 dB | 95 dB |
| Output Impedance | 10 GΩ | 50 MΩ | 100 MΩ |
| Gain | 100 V/V | 64 V/V | 12 V/V |
| Feature | Rail to rail output | 3-channel ECG | Low noise PGA & high-res ADC |
| Price | $ 19.95 (board) | $ 125 (evaluation board) | $ 7.96 (chip) |

### 2.1.3 ECG Electrode Cable

ECG Electrode cables are 24 inches long with three conductor sensor cables and electrode pad leads. It features a 3.5mm audio jack on one side and snap type receptacles at the other side. The three cables are color coded to distinguish between the positions they need to be placed for perfect results.

Figure: ECG Electrode Cables.

### 2.1.4 Self-Adhesive Electrode Pads

The Self-Adhesive Electrode Pads are reusable electrodes which contain high quality biocompatible hydrogel and is an excellent conductor. An electrode is a conductive pad in contact with the body that makes an electrical circuit with the electrocardiograph. It connects to the pad leads at the end of an ECG Electrode Cable. The main function of the electrodes is to pick up electrical signals from the human body. The ECG sensor then processes the signal and gives a graph of the electrical signal produced due to the beating of a heart.

Figure: Self-Adhesive Electrode Pads

### 2.1.5 Sparkfun pulse sensor

This pulse sensor was designed using APDS-9008 low powered light photo sensor that received reflectance from green light source at user's finger and the same green super bright reverse mount LED from Kingbright (AM2520ZGC09). It provides diode protection on the power line, so that it does not break if plugged in backwards.

It has an active filter to make the pulse waveform brighter and easy for Arduino to find. The cable is a 24” flat color coded ribbon cable with 3 male header connectors. [20] Green led produces 530 nm wavelength, which is most suitable for reacting with the blood melanin inside microvascular bed of tissue and provides better waveform. [18]

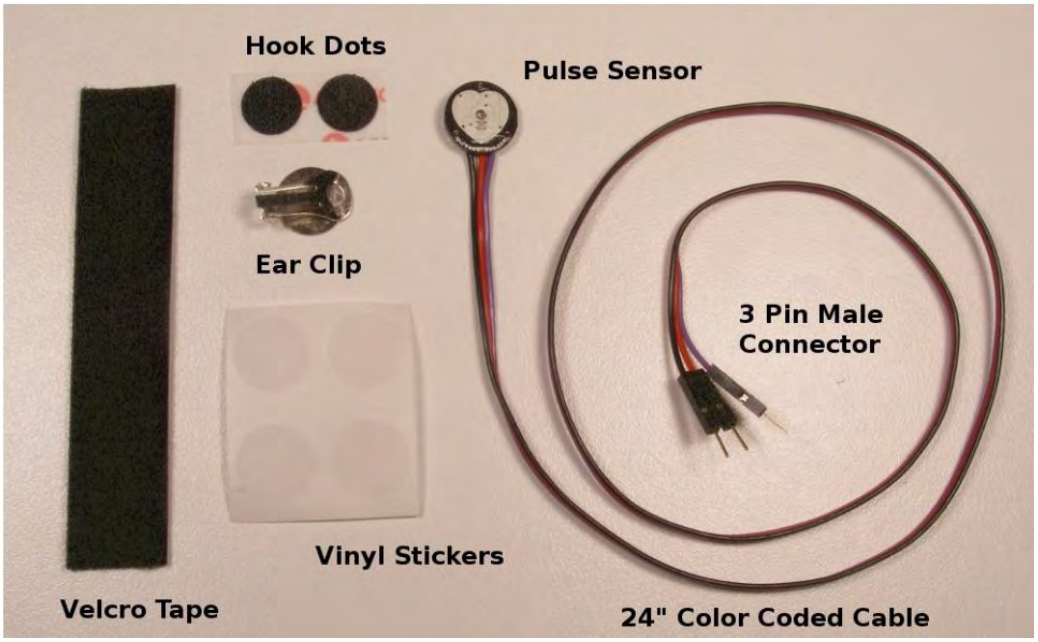


Figure: Sparkfun pulse sensor with accessories.

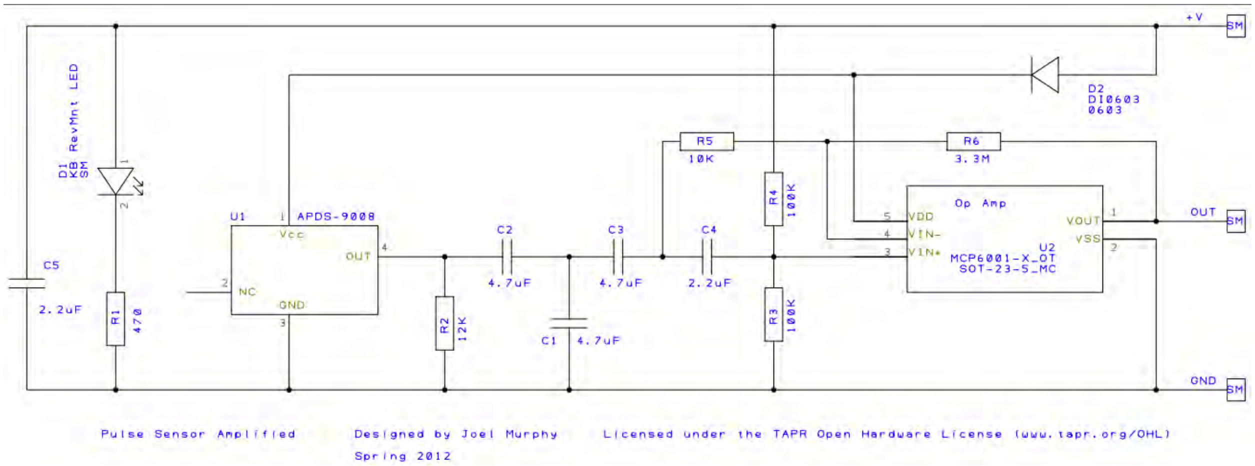


Figure: Schematics of Sparkfun pulse sensor

### 2.1.6 MAX 30105

The MAX30105 is a high-sensitivity pulse oximeter sensor. It uses LEDs, photodetectors, optical elements, and low-noise electronics with ambient light rejection. This sensor is small enough to be used with wearables and mobile devices. The operating voltage is 1.8V and a separate 5.0V for the internal LEDs. MAX30105 uses standard $I^2C$ compatible interface to communicate with the Arduino. The sensor compares the reflected infrared light and red light determining the SpO2 reading. Figure 3.1 shows the MAX30105 sensor.

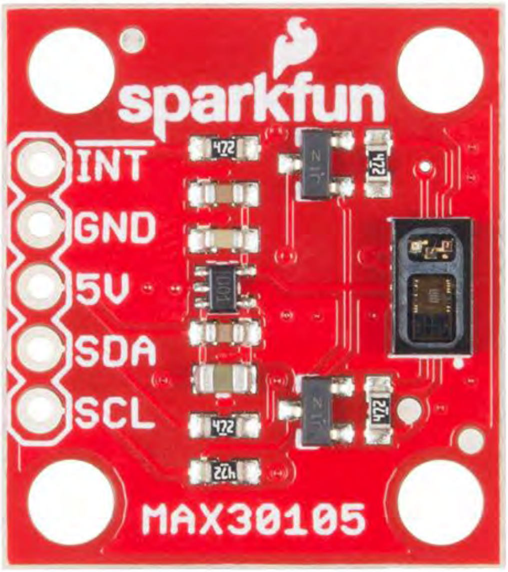


Figure 3.1: MAX30105 Sensor.

Functional diagram of the MAX30105 shown in Figure 3.2.

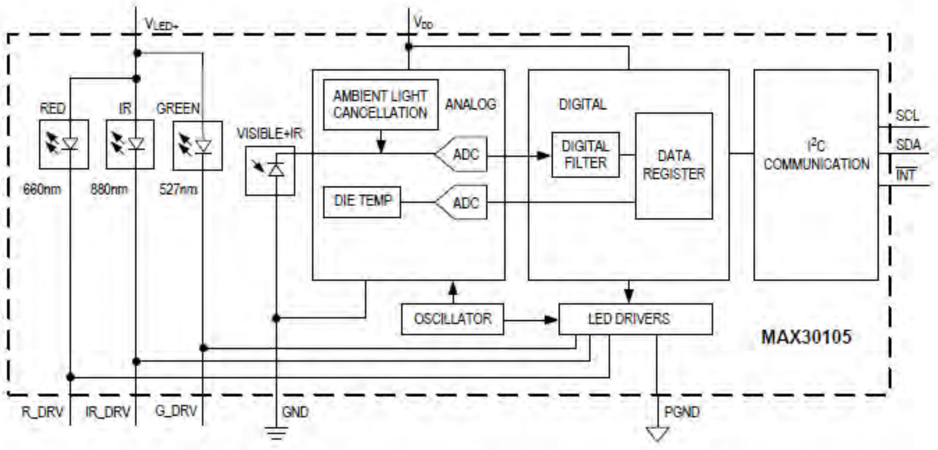


Figure : MAX30105 Functional Diagram.

MAX30105 characteristics are shown in Table below.

| PRAMETER | SYMBOL | UNIT |
|---|---|---|
| Power-Supply Voltage | $V_{DD}$ | 1.7-2.0 V |
| LED Supply Voltage | $V_{LED+}$ | 3.1-5.25 V |
| Supply Current | $I_{DD}$ | 600-1100 µA |
| Supply Current in Shutdown | $I_{SHDN}$ | 600-1100 µA |

Table: MAX30105 characteristics

### 2.1.7 Bluetooth Module HC-05:

HC-05 is designed for transparent wireless serial connection setup through the use of Bluetooth. The Bluetooth SPP (Serial Port Protocol) module uses the fully capable Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It contains a CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). HC-05 has longer range communication compared to other cheap Bluetooth Modules. It is also easy to setup and as data transfer device it is very stable. In this project this functions as the medium through which an Android device can communicate with the Arduino. The data taken from the sensor is processed by Arduino and then transfers it to the Android device through Bluetooth Module HC-05.

**Specifications**

Hardware features

i. Typical -80dBm sensitivity
ii. Up to +4dBm RF transmit power
iii. Low Power 1.8V Operation ,1.8 to 3.6V I/O
iv. PIO control
v. UART interface with programmable baud rate
vi. With integrated antenna
vii. With edge connector

Figure: Bluetooth Module HC-05

# Chapter 3

# System Overview

## 3.1 INDIVIDUALLY FEATURE IMPLEMENTATION DESCRIPTION

### 3.1.1 ECG

### 3.1.1.1 ECG BLOCK DIAGRAM

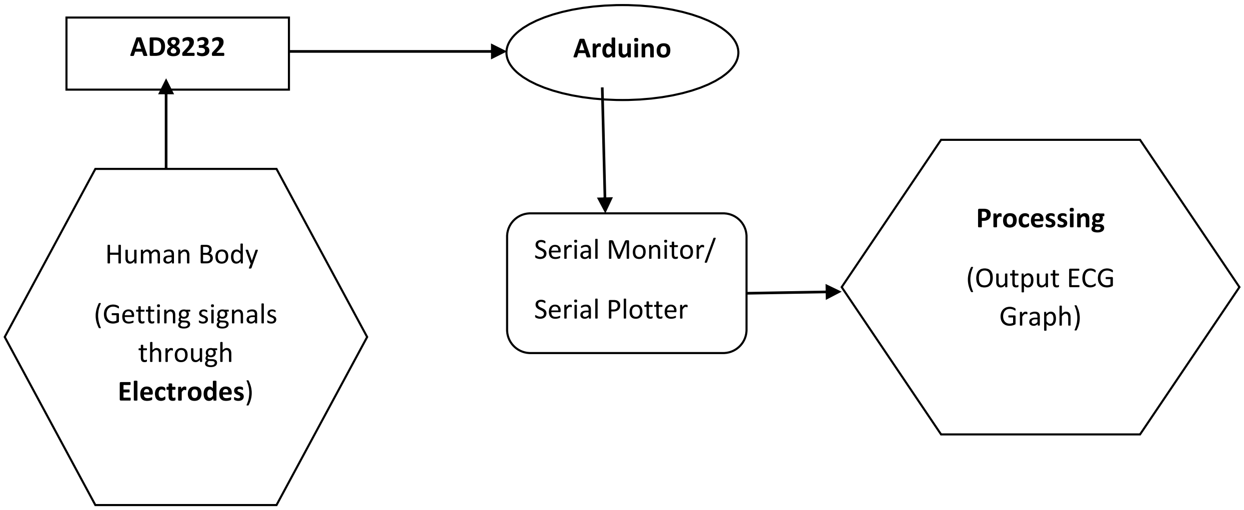


**Figure: ECG block diagram.**

### 3.1.1.2 ECG WORKING DISCRIPTION

For heart muscle depolarization electrical activity is generated which is recorded by ECG. These electrical activities propagate in pulsating electrical waves towards the skin [21]. By attaching electrodes in chest, arms and legs these electrical waves can be sensed. These electrodes are typically wet sensors, requiring the use of a conductive gel to increase conductivity between skin and electrodes. [22] They have three connectors (Ground, output and power) which need to be placed exactly same as shown in the figure below. The figure below is for single lead ECG. For 12 lead ECG the electrodes have to be placed in 12 different ways.

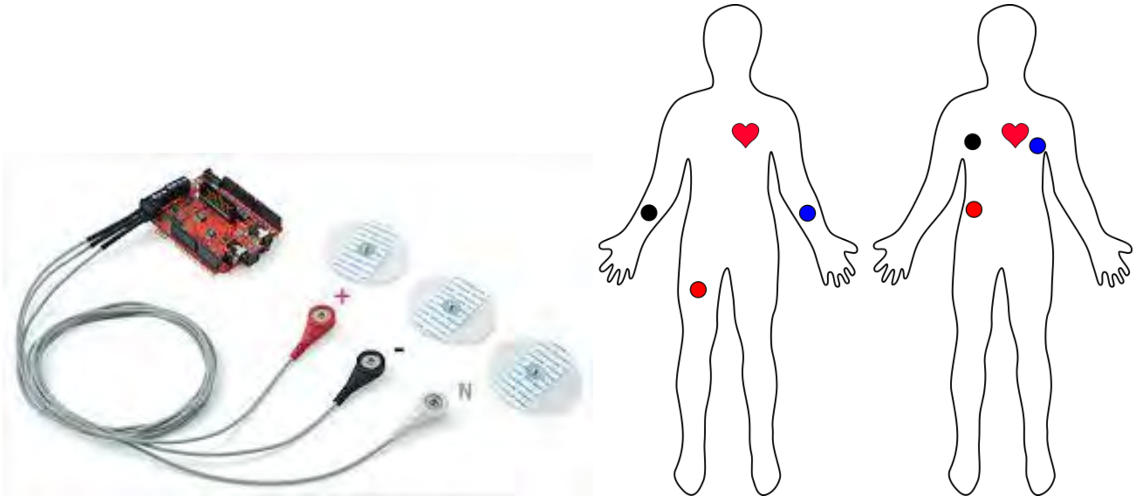


**Figure: Electrodes and electrodes placement in human body.**

The signals from electrodes then pass through AD8232 where it measures the electrical activity of the heart. AD8232 acts as an op-amp to retrieve clear signals easily. It extracts, amplifies and filters small bio-potential signals in noisy conditions such as those created by motions or remote placement of electrodes. [23]

AD8232 sends the value to arduino. The pin configuration between AD8232 and arduino has been given below:

| **AD8232** | **ARDUINO** |
|---|---|
| GND | GND |
| 3.3V | 3.3V |
| OUTPUT | A1 |
| LO- | 11 |
| LO+ | 10 |

TABLE: Pin configuration between arduino and AD8232

The process is controlled by arduino and the data can be shown in serial monitor/ serial plotter. An interface has been designed using software called 'Processing' to display the ECG graphs.

### 3.1.2 PPG

#### 3.1.2.1 PPG BLOCK DIAGRAM

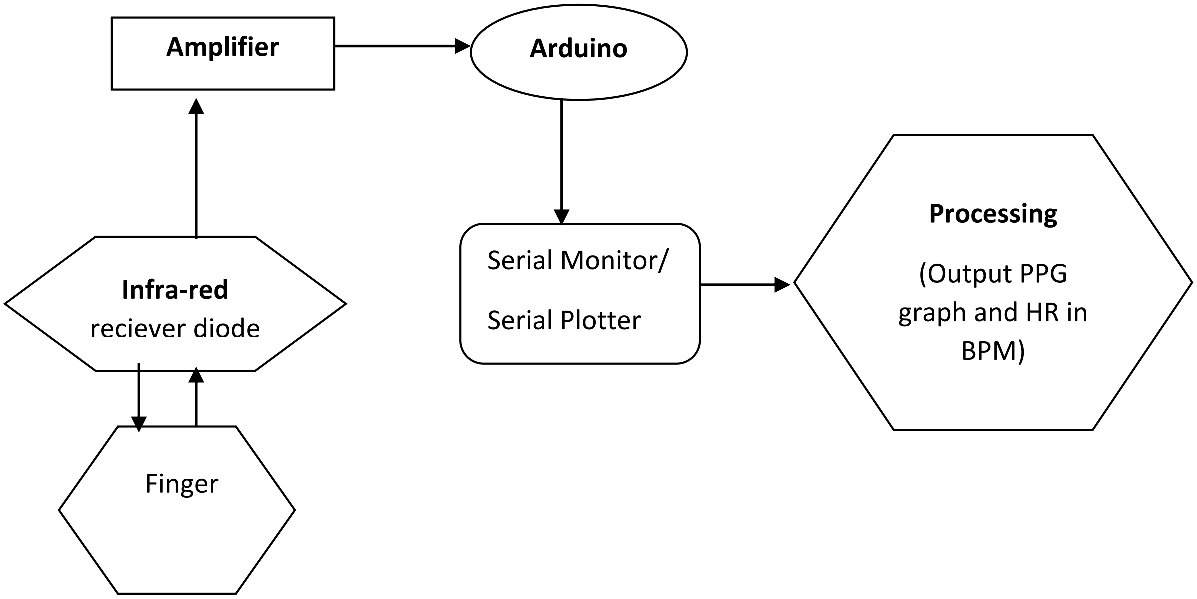


Figure: PPG block diagram.

#### 3.1.2.2 PPG WORKING DESCRIPTION

The IR transmitter sends an IR radiation which is reflected on muscles and a potential difference is created across the ends. This passes through an amplifier where it amplifies and filtered in clear signal.

Then the signal output has been sent to arduino to be controlled. The sensor has three connectors (GND, OUTPUT and INPUT POWER VOLTAGE). Pin configuration between pulse sensor and arduino has been given below:

| **PULSE SENSOR** | **ARDUINO** |
|---|---|
| GND | GND |
| OUTPUT | A0 |
| POWER | 5V |

TABLE: Pin configuration between arduino and pulse sensor.

The results from arduino can be displayed on serial monitor/ serial plotter. An interface has been designed in ‘Processing’ which shows the PPG graph, heart rate and inter-beat interval (IBI).

### 3.1.3 SpO2 AND TEMPERATURE

#### 3.1.3.1 SpO2 AND TEMPERATURE BLOCK DIAGRAM

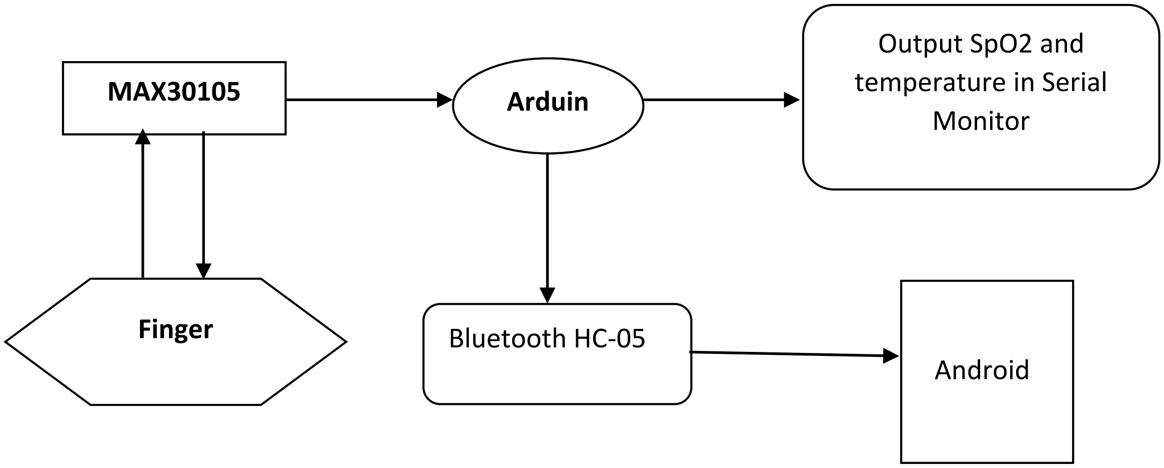


Figure: SpO2 and temperature block diagram

#### 3.1.3.2 SpO2 AND TEMPERATURE OBTAINING DESCRIPTION

With the help of infra-red SpO2 and temperature of human body can be sensed and passed through the max30105 where obtained signals amplified and filtered in clear signal.

The process is controlled by arduino. Pin configuration has been given below:

| **MAX30105** | **ARDUINO** |
|---|---|
| GND | GND |
| 5V | 5V |
| SDA | A4(or SDA) |
| SCL | A5(or SCL) |

TABLE: Pin configuration between Arduino and max30105.

The output results are later shown on serial monitor and on the android device which is connected to the arduino via Bluetooth HC-05 module.

| **Bluetooth Module** | **Arduino** |
|---|---|
| GND | GND |
| VCC | 3.3V |
| TX | Pin 10 (RX) |
| RX | Pin 11 (TX) |

Table: Bluetooth Module pin configuration

## 3.2 System

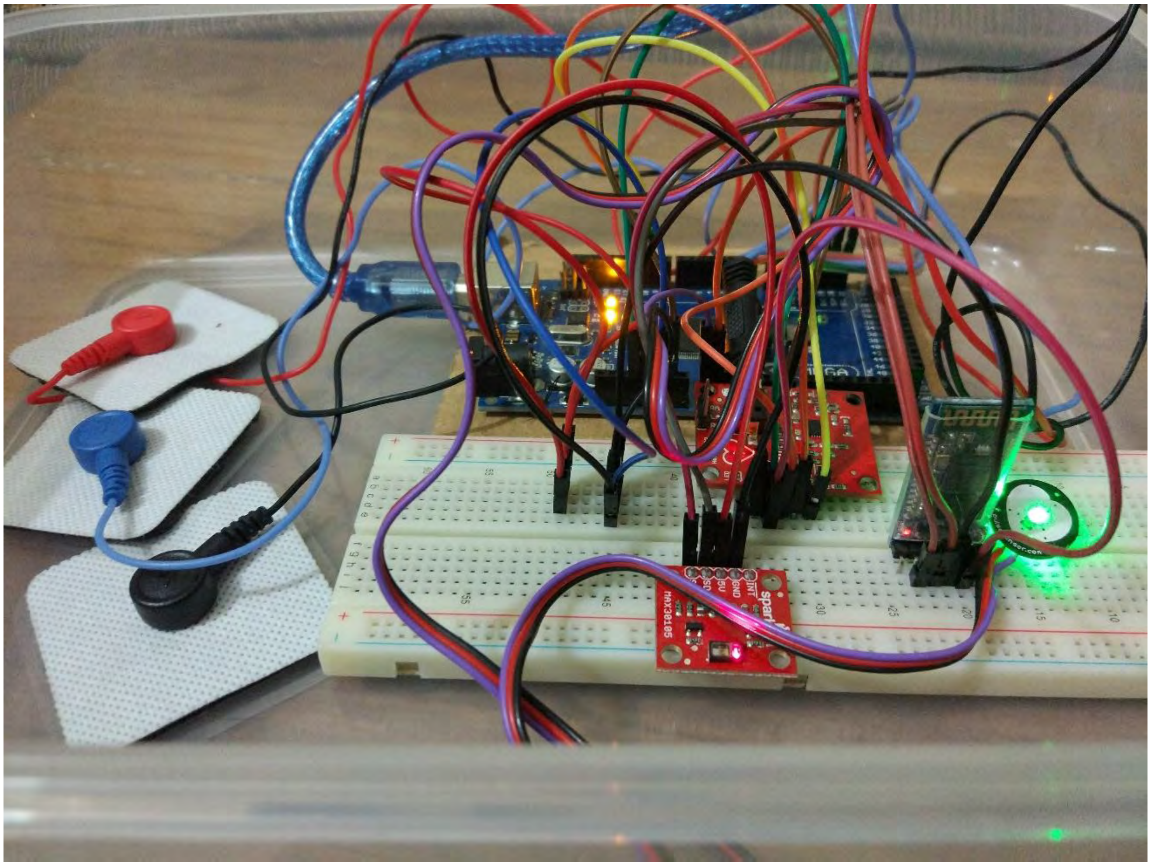


Figure: System

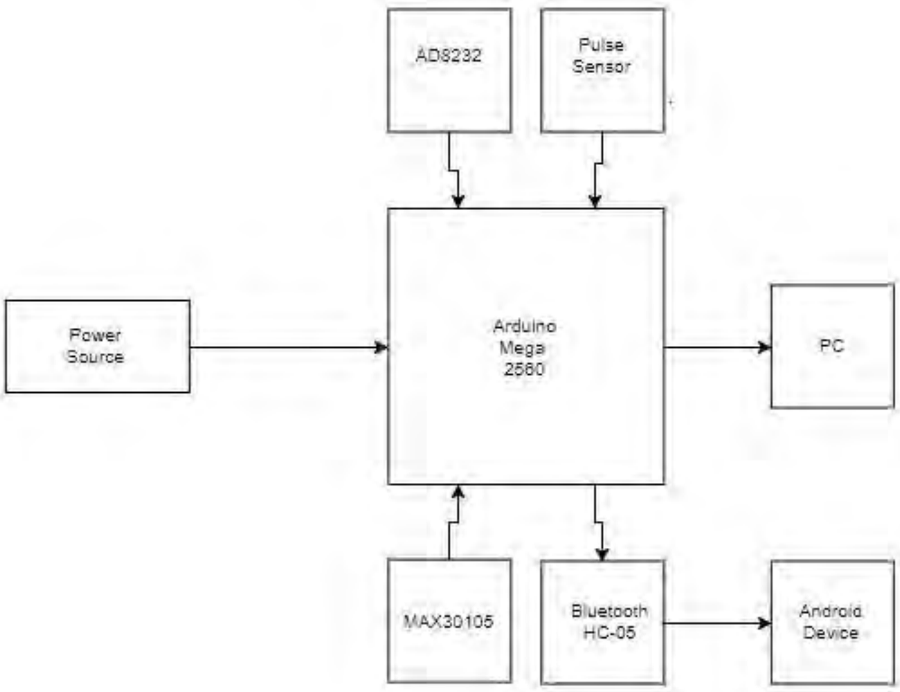


Figure: System Block Diagram

### 3.3 System Functionality:

The heart rate monitoring system has three main sensors to receive data from the human body. Each of the sensors work independently of the other sensors. All of the system is powered by a single 5V power supply. When the system powers up the user can decide and choose from many of the functionality this system offers. Which include the heart rate in BPM, SpO2 levels in percentage, interbeat interval (IBI), ECG, and body temperature in °C or °F. After the user has selected from the offered functions the system collects that individual data and displays it on a screen.

The pulse sensor is used to measure the heart rate in BPM and the IBI value. To take these data the pulse sensor is place on the finger of an individual. The sensor then relays the data received from the individual to the Arduino, the Arduino then processes the data and gives the visual representation of the data on a screen.

The AD8232 sensor is used to perform the ECG. For a complete diagnosis modern machines use 12 lead ECG and as our sensor only contains a single lead. To compensate for this problem we have to take seven different readings from seven different places. For this the user needs to use three electrodes and place them on an individual in specific places which are shown in the Figure below.

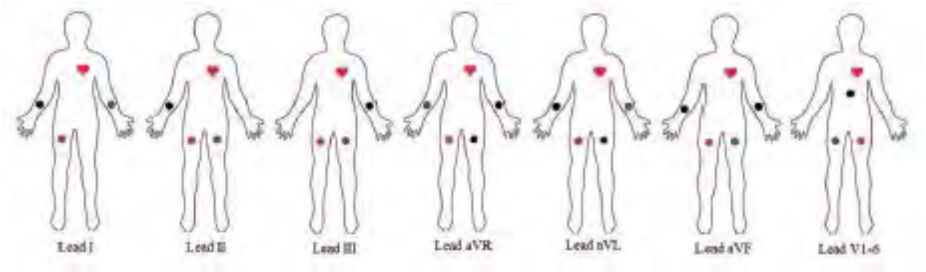


Figure: Positions for 12 lead ECG.

The placements need to be precise to get accurate and error free reading. After the electrodes are placed the sensor receives electrical signals from the body as the heart beats and sends them to Arduino. Which is then processed and displayed on the screen.

To take the SpO2 and body temperature reading we have used the MAX30105 sensor. For this sensor to work it is placed on the finger of an individual. After the collected data is processed by the Arduino it is displayed on the screen.

Our device contains two different methods to display the data from the device. One of them is that the received data is processed and displayed on PC directly from the Arduino. While the other method uses the Bluetooth module HC-05 which can connect to an Android device using Bluetooth and show the data on the Android device.

### 3.4 Software and Apps

To design our system we had to use multiple software and apps. They are Arduino IDE, Processing and Bluetooth Terminal HC-05. These software were very useful during our time designing the system.

Arduino IDE is the software which is used to code and run an Arduino Board. It is the most fundamental software which is required when using Arduino Boards. It is easy to understand and write code in. This was used to write the code that was used in our system.

Processing is an open source program and a development tool. The main function of this software is to code within the context of visual art. It has multiple examples to learn from. Data can be represented in 2D, 3D or PDF depending on the user’s requirements. It can also be used to access the Arduino from a PC and act as a display which was done in our project.

Bluetooth Terminal HC-05 is an app designed for Android devices. It was used to communicate with the Arduino through Bluetooth Module HC-05. It is very useful as it can read serial data from the Arduino which is then displayed by the app on an Android device.

## 3.5 System Flow Chart

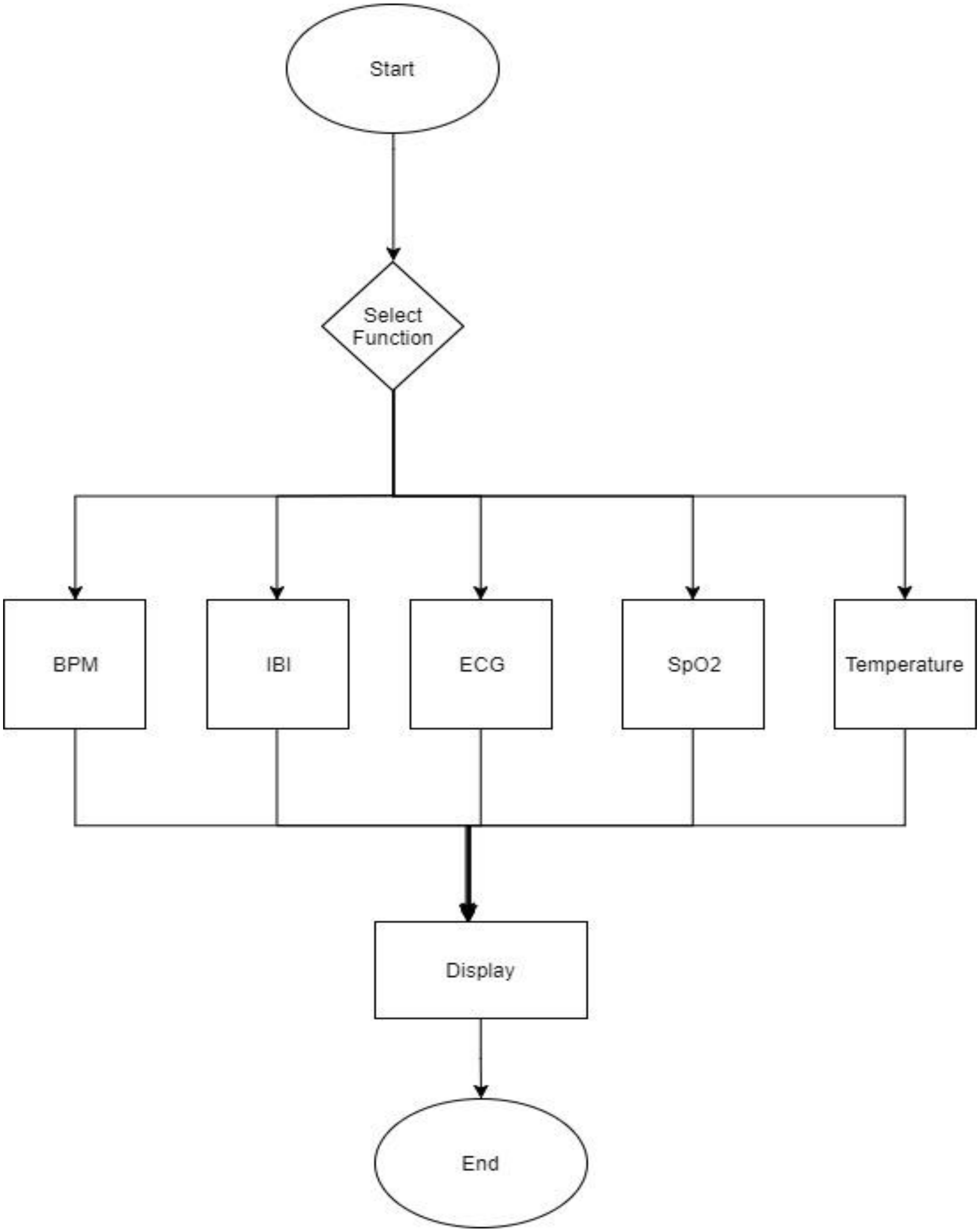


Figure: System Flow Chart

# CHAPTER 4

# DESIGN ANALYSIS

## 4.1 INDIVIDUAL FEATURE DESIGN ANALYSIS

### 4.1.1 ECG DATA ANALYSIS

Electrodes are placed in the following manner to obtain 12 lead ECG. For lead V1-6 we have to place the electrodes in 6 different place as shown in figure below.

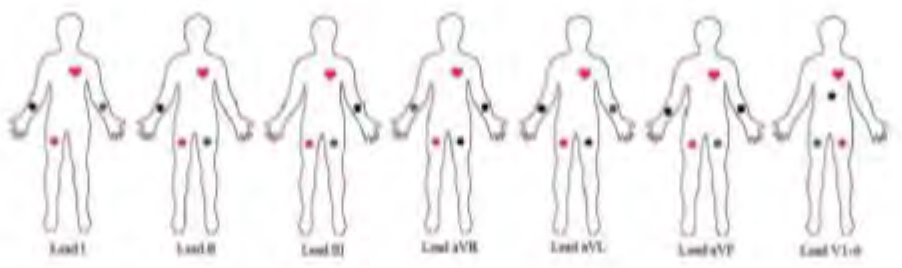


Figure: Positions for 12 lead ECG.

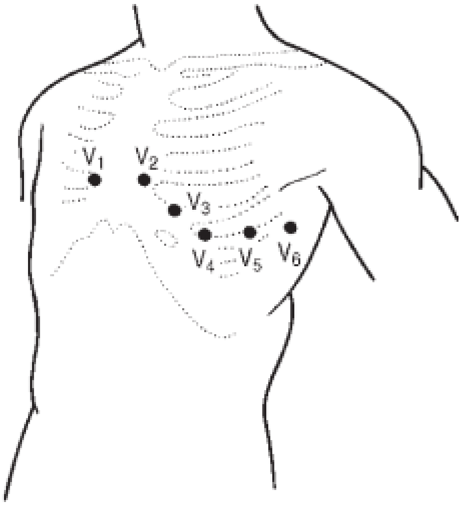
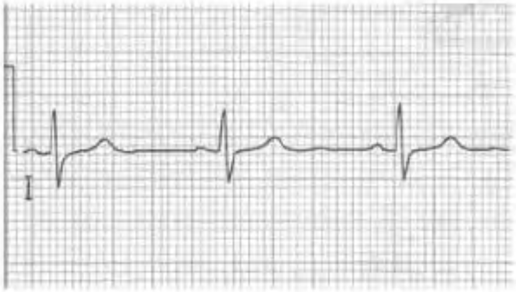
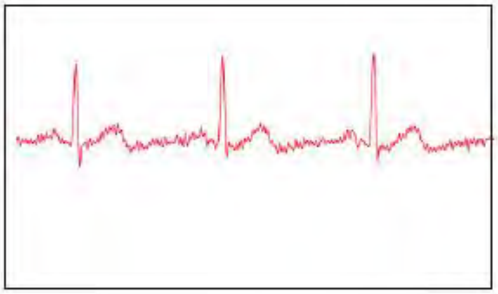


Figure: Lead V (1-6)

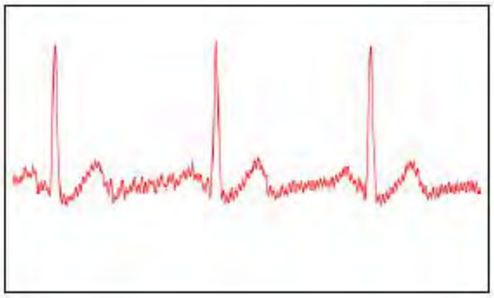
According to the comparison between 12 lead ECG obtained from medical device and the graphs that we obtained, some noise are noticeable from the graphs that we have got. This noises occurred due to movement of body. Keeping the noises aside, graphs that we obtained are almost alike to the graphs obtained from medical device except lead V1. Lead V1 results opposite to expected lead V1. All the ECG data taken from electrodes are provided in the next page.

I:

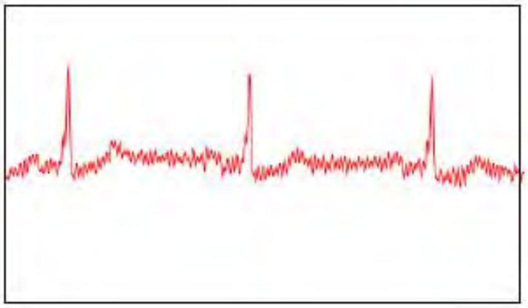




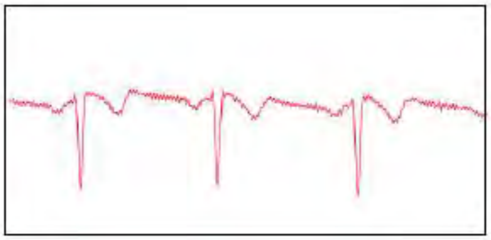
II:



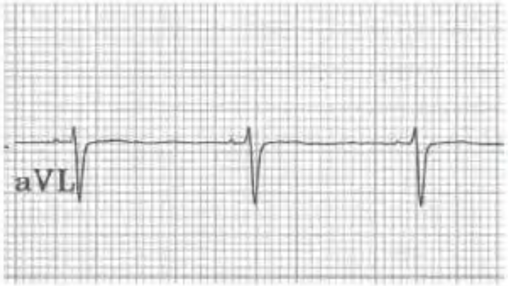
III:

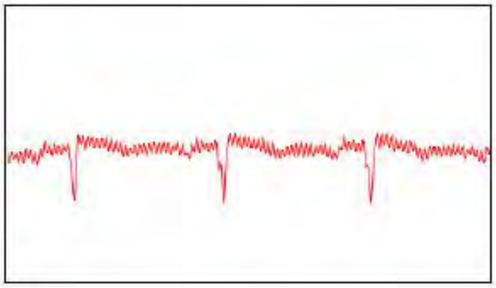


aVR:

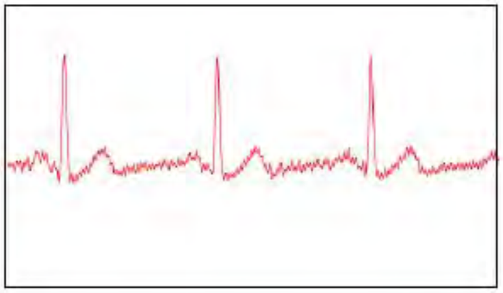


aVL:

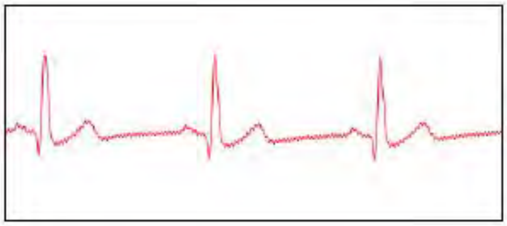




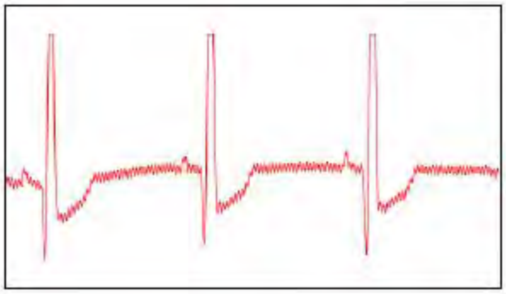
aVF:



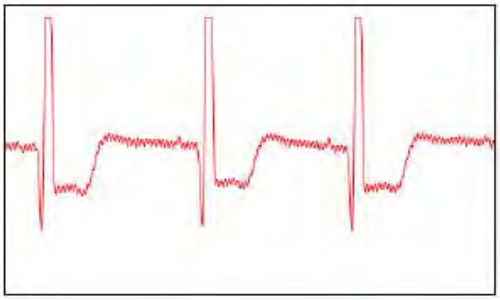
V1:



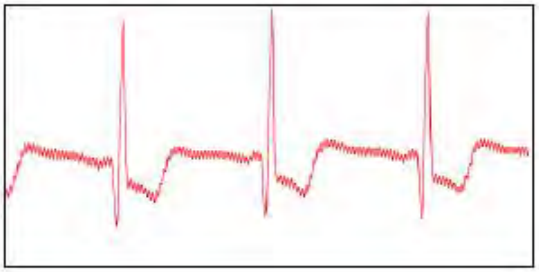
V2:



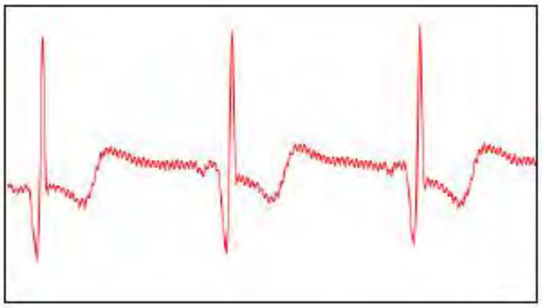
V3:



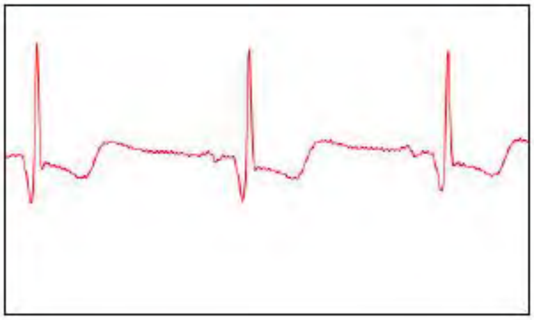
V4:



V5:



V6:



### 4.1.2 PPG DATA ANALYSIS

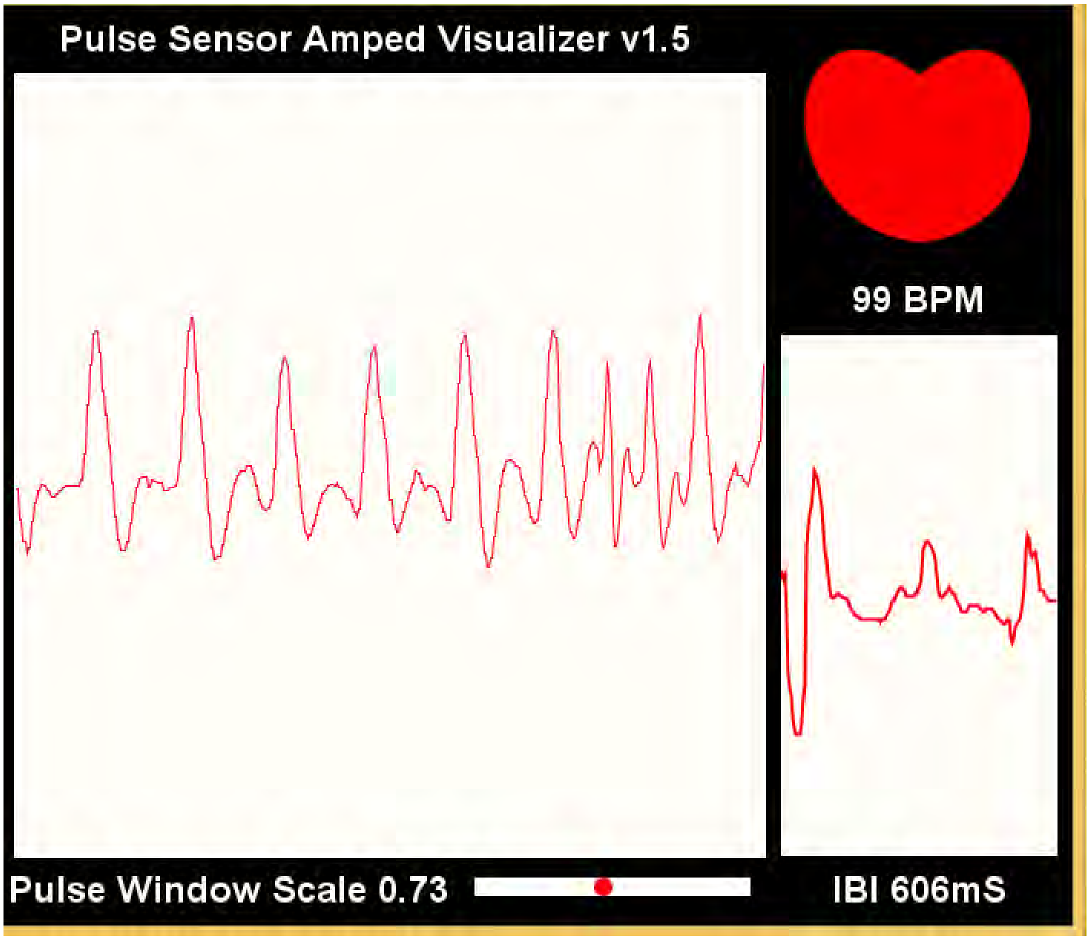


Figure: Pulse wave with Heart rate in BPM.

The figure refers the output of pulse sensor. The right below corner shows IBI trace in millisecond and in the middle below shows the window scale.

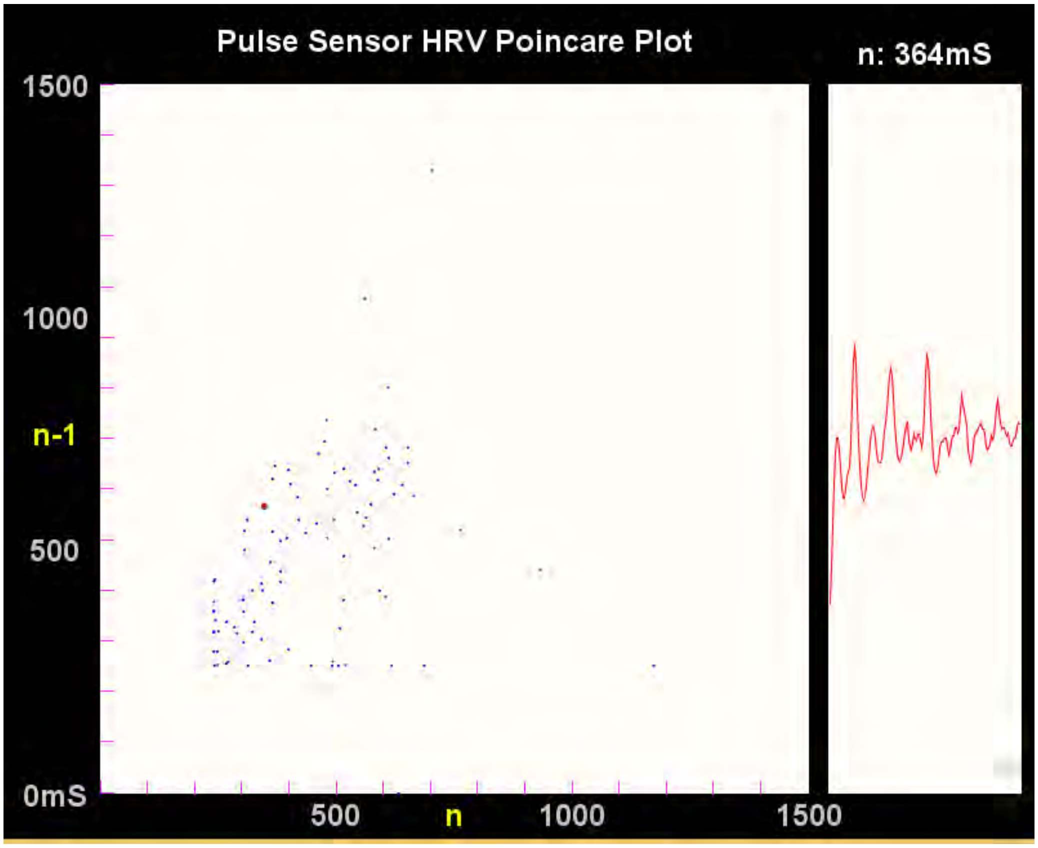


Figure: Pulse sensor HRV poincare plot

The poincare plot code takes a geometric look at the changing IBI. This graphs the current data point against the previous data point in a cartesian coordinate system. The figure shows the heart rate variability of obtained result. In the normal pulse wave these points vary a lot. But in unusual pulse wave these points gather in a single area. The red dot represents the new IBI data sent from arduino. frequency domain

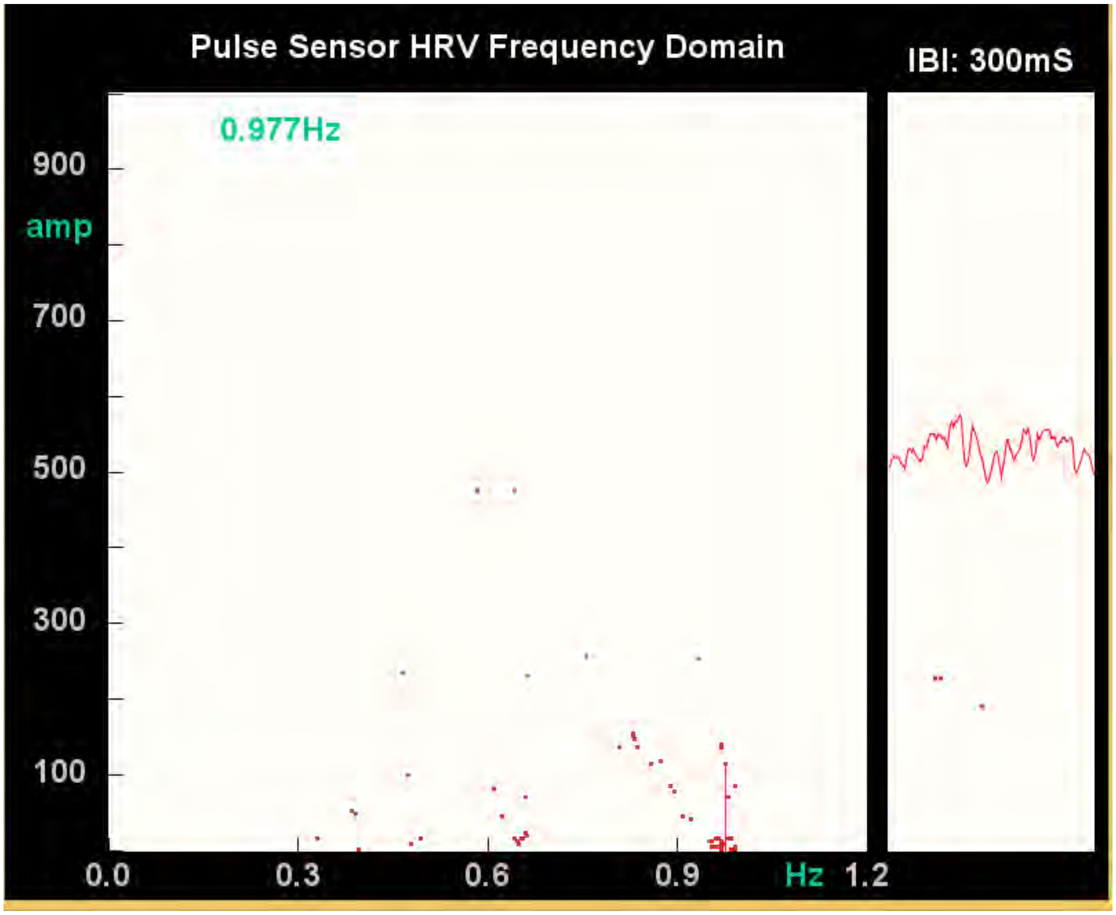


Figure: Pulse sensor HRV frequency domain.

Likewise HRV poincare plot, the scattered point refers the normal pulse wave. Abnormality happens when these points gather in a single area.

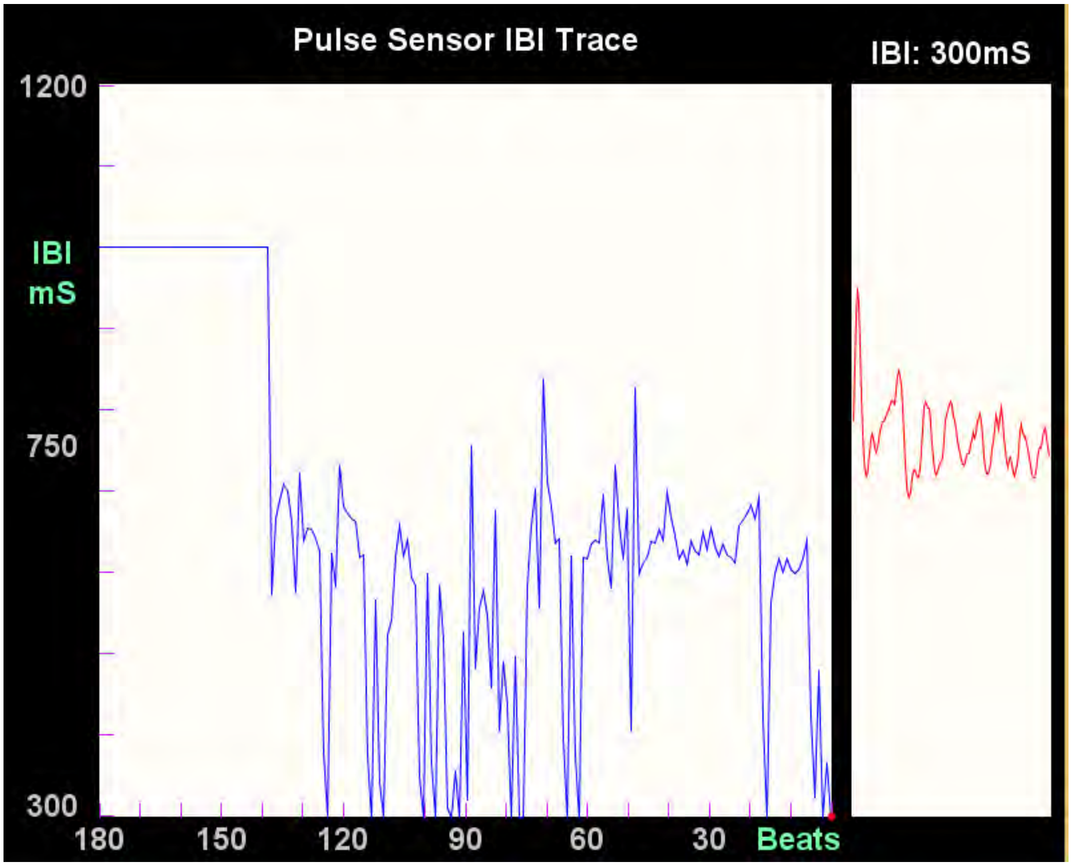


Figure: The IBI trace of pulses sensor.

The figure represents the live IBI value (inter-beat-interval) from which we can see the difference in HRV.

| AGE | AVERAGE HEART RATE IN BPM | AVERAGE EXPECTED HEART RATE RANGE IN BPM |
|---|---|---|
| 0-5 | 110 | 70-130 |
| 6-10 | 99 | 75-115 |
| 11-20 | 92 | 60-100 |
| 21-30 | 81 | 60-110 |
| 31-40 | 83 | 60-110 |
| 41-50 | 78 | 50-105 |

Table: Heart rate for different ages.

### 4.1.3 SpO2 Results.

The SpO2 results obtain from MAX30105 has been given below:

| AGE | AVERAGE SPO2 in% | EXPECTED SPO2 in % |
|---|---|---|
| 0-5 | 96 | 93-99 |
| 6-10 | 96 | 97-99 |
| 11-20 | 95 | 97-99 |
| 21-30 | 96 | 96-98 |
| 31-40 | 93 | 96-98 |
| 41-50 | 92 | 96-98 |

### 4.1.4 Temperature Results

According to a paper published on temperature from the fingertips the following data was collected. [29]

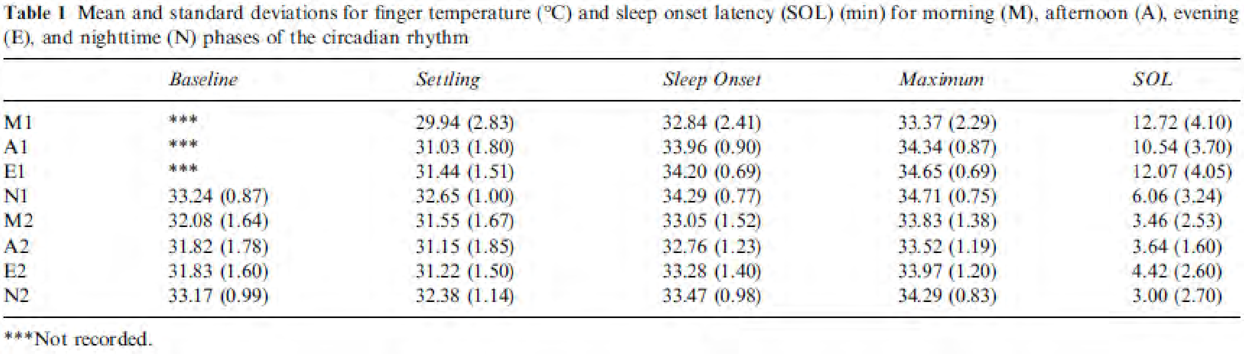


**Table 1** Mean and standard deviations for finger temperature (°C) and sleep onset latency (SOL) (min) for morning (M), afternoon (A), evening (E), and nighttime (N) phases of the circadian rhythm

| | *Baseline* | *Settling* | *Sleep Onset* | *Maximum* | *SOL* |
|---|---|---|---|---|---|
| M1 | *** | 29.94 (2.83) | 32.84 (2.41) | 33.37 (2.29) | 12.72 (4.10) |
| A1 | *** | 31.03 (1.80) | 33.96 (0.90) | 34.34 (0.87) | 10.54 (3.70) |
| E1 | *** | 31.44 (1.51) | 34.20 (0.69) | 34.65 (0.69) | 12.07 (4.05) |
| N1 | 33.24 (0.87) | 32.65 (1.00) | 34.29 (0.77) | 34.71 (0.75) | 6.06 (3.24) |
| M2 | 32.08 (1.64) | 31.55 (1.67) | 33.05 (1.52) | 33.83 (1.38) | 3.46 (2.53) |
| A2 | 31.82 (1.78) | 31.15 (1.85) | 32.76 (1.23) | 33.52 (1.19) | 3.64 (1.60) |
| E2 | 31.83 (1.60) | 31.22 (1.50) | 33.28 (1.40) | 33.97 (1.20) | 4.42 (2.60) |
| N2 | 33.17 (0.99) | 32.38 (1.14) | 33.47 (0.98) | 34.29 (0.83) | 3.00 (2.70) |

***Not recorded.

The MAX30105 sensor produced similar results when measuring temperature from the fingertips as shown below.

```
SPO2=99temperatureC=34.6875
temperatureF=94.4375,
SPO2=99temperatureC=34.6250
temperatureF=94.3250,
SPO2=99temperatureC=34.5000
temperatureF=94.1000,
SPO2=99temperatureC=34.5625
temperatureF=94.2125,
SPO2=99temperatureC=34.5625
temperatureF=94.2125,
SPO2=99temperatureC=34.6250
temperatureF=94.3250,
SPO2=99temperatureC=34.6250
temperatureF=94.3250,
SPO2=99temperatureC=34.5625
temperatureF=94.2125,
SPO2=99temperatureC=34.6875
temperatureF=94.4375,
SPO2=99temperatureC=34.6875
temperatureF=94.4375,
```

# Chapter 5

# Future Work and Conclusion

## 5.1 Future work

For the future we plan on adding a touch screen display, data streaming and implementation on a PCB board. The touch screen display would ease the use of our device greatly as it would provide simple interface to navigate through all the functionalities. In a developing country like Bangladesh many areas do not have internet connection, but in the near future we hope to see a country where everyone has access to internet. We plan to use this opportunity to implement data streaming to our device, through which any doctor can provide their medical expertise from a distant area. Data streaming would use the internet to stream the collected data to a PC or a device that has access to internet. Our designed system takes up a lot of space due to the use of many sensors, breadboards and microcontroller boards separately. Through the use of PCB boards we can reduce the space taken by our device which would make the device more portable.

## 5.2 Conclusion

Our device in its current version cannot provide medical grade diagnosis of any diseases. It can only provide an approximation to diagnose a disease, for better treatment medical grade instruments must be used. The data we have collected were taken by inexperienced individuals and as such the data collected was not as accurate as possible, but in the hands of an experienced medical professional the results are expected to be more accurate. As we have shown in previous chapters that our device can provide adequate cardiovascular health care. To conclude, this device can help the low income and poor families of Bangladesh to get better and cheaper cardiovascular health care. A price comparison between other available devices and our device is shown below.

Our device:

| **Sensors** | **Price ($)** |
|---|---|
| Arduino Mega 2560 | 7.27 |
| ECG Sensor (AD8232) | 12.50 |
| Pulse sensor | 24.95 |
| MAX30105 | 12.95 |
| Bluetooth Module HC-05 | 11.00 |
| Electrode 10 Pack | 16.11 |
| Electrode Cable | 14.99 |
| **Total** | 99.77 |

Comparable Devices:

| **Name Of Device** | **Features** | **Price ($)** |
|---|---|---|
| Scanadu Scout | Heart rate, skin and body temperatures, respiratory rates, blood pressure, electrocardiography, oxygen levels and emotional stress. | 199.00 |
| Qardiocore | Continuous wireless ECG, heart rate, respiratory rate, skin temperature, heart rate variability and activity tracking. | 449.00 |
| Patient Monitor 12.1 Inch | ECG, SpO2, body temperature, respiratory rate and pulse rate. | 499.00 |

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# Appendix

## ECG CODE:

```
void setup() {
  // initialize the serial communication:
  Serial.begin(9600);
  pinMode(10, INPUT); // Setup for leads off detection LO +
  pinMode(11, INPUT); // Setup for leads off detection LO -

}

void loop() {

  if((digitalRead(10) == 1)||(digitalRead(11) == 1)){
    Serial.println('!');
  }
  else{
    // send the value of analog input 0:
      Serial.println(analogRead(A1));
  }
  //Wait for a bit to keep serial data from saturating
  delay(1); }
```

## pulse code:

```
#define PROCESSING_VISUALIZER 1
#define SERIAL_PLOTTER  2
```

```
//  Variables
int pulsePin = 0;                 // Pulse Sensor purple wire connected to analog pin 0
int blinkPin = 13;                // pin to blink led at each beat
int fadePin = 5;                  // pin to do fancy classy fading blink at each beat
int fadeRate = 0;                 // used to fade LED on with PWM on fadePin

// Volatile Variables, used in the interrupt service routine!
volatile int BPM;                   // int that holds raw Analog in 0. updated every 2mS
volatile int Signal;                // holds the incoming raw data
volatile int IBI = 600;             // int that holds the time interval between beats! Must be seeded!
volatile boolean Pulse = false;     // "True" when User's live heartbeat is detected. "False" when not a "live beat".
volatile boolean QS = false;        // becomes true when Arduino finds a beat.

// SET THE SERIAL OUTPUT TYPE TO YOUR NEEDS
// PROCESSING_VISUALIZER works with Pulse Sensor Processing Visualizer
//         https://github.com/WorldFamousElectronics/PulseSensor_Amped_Processing_Visualizer
// SERIAL_PLOTTER outputs sensor data for viewing with the Arduino Serial Plotter
//      run the Serial Plotter at 115200 baud: Tools/Serial Plotter or Command+L
static int outputType = SERIAL_PLOTTER;
```

```
void setup(){
  pinMode(blinkPin,OUTPUT);         // pin that will blink to your heartbeat!
  pinMode(fadePin,OUTPUT);          // pin that will fade to your heartbeat!
  Serial.begin(115200);             // we agree to talk fast!
  interruptSetup();                 // sets up to read Pulse Sensor signal every 2mS
   // IF YOU ARE POWERING The Pulse Sensor AT VOLTAGE LESS THAN THE BOARD VOLTAGE,
   // UN-COMMENT THE NEXT LINE AND APPLY THAT VOLTAGE TO THE A-REF PIN
//   analogReference(EXTERNAL);
}



//  Where the Magic Happens
void loop(){


    serialOutput() ;


  if (QS == true){     // A Heartbeat Was Found
                       // BPM and IBI have been Determined
                       // Quantified Self "QS" true when arduino finds a heartbeat
        fadeRate = 255;         // Makes the LED Fade Effect Happen
                                // Set 'fadeRate' Variable to 255 to fade LED with pulse
        serialOutputWhenBeatHappens();   // A Beat Happened, Output that to serial.
        QS = false;                      // reset the Quantified Self flag for next time
  }
```

```
  ledFadeToBeat();                      // Makes the LED Fade Effect Happen
  delay(20);                            //  take a break
}
void ledFadeToBeat(){
    fadeRate -= 15;                         //  set LED fade value
    fadeRate = constrain(fadeRate,0,255);   //  keep LED fade value from going into negative numbers!
    analogWrite(fadePin,fadeRate);          //  fade LED}
```

## SpO2 and Temperature with Bluetooth code:

```
Hardware Connections (Breakoutboard to Arduino):
  -5V = 5V (3.3V is allowed)
  -GND = GND
  -SDA = A4 (or SDA)
  -SCL = A5 (or SCL)
  -INT = Not connected

  The MAX30105 Breakout can handle 5V or 3.3V I2C logic. We recommend powering the board with 5V
  but it will also run at 3.3V.
*/
#include <SoftwareSerial.h>
SoftwareSerial BTserial(10, 11);// RX
#include <Wire.h>
```

```
#include "MAX30105.h"
#include "spo2_algorithm.h"

MAX30105 particleSensor;

#define MAX_BRIGHTNESS 255

#if defined(ARDUINO_AVR_UNO)
//Arduino Uno doesn't have enough SRAM to store 100 samples of IR led data and red led data in 32-bit format
//To solve this problem, 16-bit MSB of the sampled data will be truncated. Samples become 16-bit data.
uint16_t irBuffer[100]; //infrared LED sensor data
uint16_t redBuffer[100];  //red LED sensor data
#else
uint32_t irBuffer[100]; //infrared LED sensor data
uint32_t redBuffer[100];  //red LED sensor data
#endif

int32_t bufferLength; //data length
int32_t spo2; //SPO2 value
int8_t validSPO2; //indicator to show if the SPO2 calculation is valid
int32_t heartRate; //heart rate value
int8_t validHeartRate; //indicator to show if the heart rate calculation is valid

byte pulseLED = 11; //Must be on PWM pin
```

```
byte readLED = 13; //Blinks with each data read

void setup()
{
 BTserial.begin(9600);
 Serial.begin(115200); // initialize serial communication at 115200 bits per second:

 pinMode(pulseLED, OUTPUT);
 pinMode(readLED, OUTPUT);

 // Initialize sensor
 if (!particleSensor.begin(Wire, I2C_SPEED_FAST)) //Use default I2C port, 400kHz speed
 {
  Serial.println(F("MAX30105 was not found. Please check wiring/power."));
  while (1);
 }

 Serial.println(F("Attach sensor to finger with rubber band. Press any key to start conversion"));
 while (Serial.available() == 0) ; //wait until user presses a key
 Serial.read();

 byte ledBrightness = 60; //Options: 0=Off to 255=50mA
 byte sampleAverage = 4; //Options: 1, 2, 4, 8, 16, 32
 byte ledMode = 2; //Options: 1 = Red only, 2 = Red + IR, 3 = Red + IR + Green
```

```
  byte sampleRate = 100; //Options: 50, 100, 200, 400, 800, 1000, 1600, 3200
  int pulseWidth = 411; //Options: 69, 118, 215, 411
  int adcRange = 4096; //Options: 2048, 4096, 8192, 16384

  particleSensor.setup(ledBrightness, sampleAverage, ledMode, sampleRate, pulseWidth, adcRange); //Configure sensor with these settings
}

void loop()
{

  bufferLength = 100; //buffer length of 100 stores 4 seconds of samples running at 25sps

  //read the first 100 samples, and determine the signal range
  for (byte i = 0 ; i < bufferLength ; i++)
  {
    while (particleSensor.available() == false) //do we have new data?
      particleSensor.check(); //Check the sensor for new data

    redBuffer[i] = particleSensor.getRed();
    irBuffer[i] = particleSensor.getIR();
    particleSensor.nextSample(); //We're finished with this sample so move to next sample

    Serial.print(F("red="));
```

```
    Serial.print(redBuffer[i], DEC);
    Serial.print(F(", ir="));
    Serial.println(irBuffer[i], DEC);
  }

  //calculate heart rate and SpO2 after first 100 samples (first 4 seconds of samples)
  maxim_heart_rate_and_oxygen_saturation(irBuffer, bufferLength, redBuffer,
&spo2, &validSPO2, &heartRate, &validHeartRate);

  //Continuously taking samples from MAX30102.  Heart rate and SpO2 are
calculated every 1 second
  while (1)
  {
    //dumping the first 25 sets of samples in the memory and shift the last 75 sets of
samples to the top
    for (byte i = 25; i < 100; i++)
    {
      redBuffer[i - 25] = redBuffer[i];
      irBuffer[i - 25] = irBuffer[i];
    }

    //take 25 sets of samples before calculating the heart rate.
    for (byte i = 75; i < 100; i++)
    {
      while (particleSensor.available() == false) //do we have new data?
        particleSensor.check(); //Check the sensor for new data
```

```
    digitalWrite(readLED, !digitalRead(readLED)); //Blink onboard LED with every data read


    redBuffer[i] = particleSensor.getRed();
    irBuffer[i] = particleSensor.getIR();
    particleSensor.nextSample(); //We're finished with this sample so move to next sample
    float temperature = particleSensor.readTemperature();
    Serial.print("temperatureC=");
    Serial.print(temperature, 4);
    BTserial.print("temperatureC=");
    BTserial.print(temperature, 4);
    BTserial.print(" ");
    float temperatureF = particleSensor.readTemperatureF();
     Serial.print(" temperatureF=");
     Serial.print(temperatureF, 4);
     Serial.print(" ");
     BTserial.print(" temperatureF=");
     BTserial.print(temperatureF, 4);
     BTserial.print(" ");
    //send samples and calculation result to terminal program through UART
    Serial.print(F("red="));
    Serial.print(redBuffer[i], DEC);
    Serial.print(F(", ir="));
    Serial.print(irBuffer[i], DEC);
```

```
     Serial.print(F(", HR="));
     Serial.print(heartRate, DEC);

     Serial.print(F(", HRvalid="));
     Serial.print(validHeartRate, DEC);

     Serial.print(F(", SPO2="));
     Serial.print(spo2, DEC);
     BTserial.print(F(", SPO2="));
     BTserial.print(spo2, DEC);
     BTserial.print(" ");



     Serial.print(F(", SPO2Valid="));
     Serial.println(validSPO2, DEC);
    }

    //After gathering 25 new samples recalculate HR and SP02
    maxim_heart_rate_and_oxygen_saturation(irBuffer, bufferLength, redBuffer, &spo2, &validSPO2, &heartRate, &validHeartRate);
  }
}
```