A HEADPHONE BASED HEART RATE (HR) AND HEART RATE VARIABILITY (HRV) MONITORING UNIT

A THESIS

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THESIS CERTIFICATE

This is to certify that the thesis entitled "**A HEADPHONE BASED HEART RATE (HR) AND HEART RATE VARIABILITY (HRV) MONITORING UNIT"** submitted by **Mr Gashay Lewtie Hailu** (ee14m076) in a partial fulfillment of the requirement for the award of Master of Technology Degree in Electrical Engineering at Indian Institute of Technology Madras, Chennai**,** is an authentic work carried out by him under my guidance. To the best of my knowledge the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

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Abstract

Key word: Photoplethysmography (PPG); pulse rate; reflectance; transmittance; MIT App Inventor; Infrared sensor; signal conditioning circuit; filters

A new Heart Rate (HR) and Heart Rate Variability (HRV) monitoring system has been developed and presented in this thesis. The system is portable. It is integrated in a typical Head-phone. As the system is a part of the head phone, the HR and HRV are recorded without any disturbance or inconvenience to the person wearing it. The recorded data is transmitted to a cell-phone, wirelessly, and displayed. In this way, the person who is using the device will find no in-convenience especially if he/she is a headphone user.

The HR is detected using the Reflectance photoplethysmography (PPG) Technique, which is a non-invasive method to measure the alteration in blood volume in the tissue using a suitable light source and detector. The sensor unit consists of an infrared light-emitting-diode (IR LED) and a phototransistor, placed side by side in a single package. The IR diode transmits an infrared light into the surface of the body near to Ear integrated with headphone, and the phototransistor senses the portion of the light that is reflected back. The intensity of reflected light depends upon the blood volume inside the tissue. So, each heart beat slightly alters the amount of reflected infrared light that can be detected by the phototransistor. With a proper signal conditioning, this little change in the amplitude of the reflected light can be converted into almost pure PPG signal and using an ADC in the microcontroller the PPG signal is digitized. This digitized signal is then passed through an algorithm that gives a high-low pulse, from which the microcontroller can calculate the time period between two heart beats and then HRV.

The location of the optical sensor is an important design issue in this project that affects the signal quality and robustness against motion artifacts. PPG sensors are commonly worn on the fingers due to the high signal amplitude that can be achieved in comparison with other sites. However, this configuration is not suited to continuous sensing as most daily activities involve the use of the fingers. In this project to overcome this problem the sensor is integrated with the headphone on the ear pad for providing greater comfort for the user. The signal conditioning circuit also integrates on the headband. The device is powered by 5V which is taken from Intex Wireless Roaming headphone which has 2 AAA batteries each battery gives 1.5V. The

headphone gives maximum of 3V so to get the required supply voltage to the system we use DC-DC Boost Converter Step Up Module 1-5V to 5V 500mA.

An android interface has been developed and used in this project to show the data obtained in the form of beat per minute using MIT App Inventor 2 application used for Bluetooth communication. Tests conducted on various people, using the prototype system developed proved the usefulness of the scheme.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1.	PPG	Photoplethysmograph
2.	HR	Heart Rate
3.	HRV	Heart Rate Variability
4.	LPF	Low Pass Filter
5.	HPF	High Pass Filter
6.	OP AMP	Operational Amplifier
7.	LED	Light Emitting Diode
8.	IR	Infrared
9.	VI	Virtual Instrument
10.	NI ELVIS	National Instrument Education Laboratory Virtual Instrument Suite
11.	bpm	beat per minute
12.	SPP	Serial Port Protocol
13.	LCD	Liquid Crystal Display
14.	EDR	Enhanced Data Rate
15.	RC	Resistance-Capacitance
16.	ADC	Analogue to Digital Converter
17.	TTL	Transistor -Transistor Logic
18.	MRI,ECG	Magnetic Resonance Imaging, Electrocardiogram
19.	EEG	Electroencephalogram
20.	AFH	Adaptive Frequency Hopping Feature

NOTATIONS

V	Voltage
I	Current
R	Resistance
C	Capacitance
f	Frequency
μ	micro
m	milli
k	kilo
n	nano
M	Mega
Hz	Hertz
Ω	Ohm
ω	Angular frequency

CHAPTER 1

INTRODUCTION

Heart Rate (HR) and Heart Rate Variability (HRV) are important parameter of any person's cardiovascular health. The conventional method to measure heart rate is to sense the arterial pulse by manually placing fingers or thumb over the wrist. Thereafter, the sensed pulse is counted and beats per minute (bpm) is estimated. However, this method is not suitable for continuous monitoring. When the pulse rate is high or irregular, it becomes more susceptible to error. Clinically, more advanced methods like Electro-cardiogram (ECG) are employed for measurement of heart beat. Although accurate results are obtained, these methods are uneconomical and complex in nature. This calls for a device that is economical, dependable and also easily used for continuous monitoring.

There are two ways in which heart monitors can be developed: Electrical and Optical. Optical method is advantageous over the electrical method. Firstly, there is no electrical contact in optical systems making it safer. Secondly, unlike electrical method, there is less electromagnetic interference in the detected signal. The optical method makes use of the concept of Photoplesthysmography (PPG). It measures the relative changes in blood volume from body tissues. These changes in volume cause the amount of incident light to modulate [1]. In this project we develop a heart rate measuring device employing an optical sensor which makes use of an Infrared diode and Phototransistor to extract pulse signals. When the heart pumps, a pulse of blood flows through the blood vessels and the finger becomes slightly opaque. Consequently, less Infrared light is received by the Phototransistor. Along with the pulse signals, unwanted noise is obtained. A signal conditioning circuit is used to remove this interference. The filtered signal is then amplified and converted into a digital signal whose frequency is calculated using a microcontroller [1].

Heart Rate (HR) monitoring system integrated with headphone is low cost device has Bluetooth interfaced with the microcontroller that displays the pulse rate using android device. If the microcontroller is programmed and connected to android application developed using app inventor 2 accordingly, an added advantage is that user will be able to see average, maximum or minimum rates of the beat rate per minute. Everybody can now measure and analyze their heart rate in home environment as well.

1.1. PURPOSE/APPLICATION OF THIS PROJECT

The design for this product is geared to produce a device that can act as continuous monitoring of Heart Rate (HR) and Heart Rate Variability (HRV) with low disturbance. In addition, this devise used as a drowsy detection, medical purpose, anger detection and personal trainer etc. Without the constant checking of your own heart rate, the user is able to focus entirely on running, driving or pedaling and doing some other exercise using his/her android phone. With the device being less expensive, portable and more safe than constantly monitoring yourself, this improved method of exercise shapes the future of driving, training and exercising. In addition, it reflects different physiological conditions such as biological workload, stress at work and concentration on tasks, and the active state of the autonomic nervous system.

1.2. OBECTIVE AND SCOPE OF THE PROECT

The foremost objective of this project is to develop a prototype for a portable and low cost heart rate monitoring system that detects the blood volume pulsation using photoplethysmograph (PPG) sensor integrated with headphone, calculate Heart Rate per minute, Heart Rate Variability and display the result with android device using Bluetooth communication. The design norms for heart rate monitoring system comprise of the PPG sensor selection, positioning of the sensor, integration of the sensor with headphone and hardware development for signal conditioning.

In view of the above requirements the objective of the project can be stated as below:

- Select the PPG sensor and integrate with headphone.
- Decide the position of the sensor to get good PPG signal.
- Extract and amplify the PPG signal coming from phototransistor using signal conditioning circuit.
- Digitalize PPG signal using arudino uno analog to digital converter.
- Calculate the heart rate per minute from digitized PPG signal using Arudino uno.
- Display the result on Android device using Bluetooth communication

1.3. ORGANISATION OF THE THESIS

Chapter -1 presents the theory, objective the design and development of heart rate monitoring system. It also elaborates the need/ application and specification of this project.

Chapter-2 discusses, in detail, back ground, type and basic principle of the photoplethysmograph (PPG) sensor and optical properties of skin.

Chapter -3 deals the design and development of hardware system. Step-by-step progress of the project has been elaborated in this chapter supported with the related figures and waveforms, as required.

Chapter -4 discusses about Android application. In this chapter briefly explain how to create android application using MIT APP INVENTOR 2 which is a web-based online graphical mobile application.

Chapter-5 explains the Virtual Instrument developed for the circuit in LabVIEW environment. Details of the circuit prototypes developed in the lab along with the experimental results are also discussed.

In Chapter-6, conclusions and summary have been drawn on the present work and scope of the future work has been presented.

CHAPTER 2

BACKGROUND THEORY OF PHOTOPLETHYSMOGRAPHY (PPG)

2.1. PHOTOPLETHYSMOGRAPHY (PPG)

Plethysmography is a technique of measuring the blood volume changes in any part of the body that result from the pulsation of blood occurring with each heartbeat. Photoplethysmography (PPG) is the electro-optic technique of measuring the cardiovascular pulse wave found throughout the human body. The pulse wave is caused by the periodic pulsations of arterial blood volume and is measured by the changing optical absorption, which this induces. Photoplethysmography (PPG) technology has been used to develop small, wearable, pulse rate sensors. These devices, consisting of infrared light-emitting diodes (LEDs) and photodetectors offer a simple, reliable, low-cost means of monitoring the pulse rate noninvasively. Recent advances in optical technology have facilitated the use of high-intensity green LEDs for PPG, increasing the adoption of this measurement technique [2].

PPG uses inexpensive optical sensors, which are rugged, and needs little maintenance. Since it consumes very less power and can be powered by a battery pack in this project 5V power supply sufficient, it is an ideal portable device. The PPG signal contains a rich source of information related to the cardio pulmonary system. In recent years, multi-wavelength application of arterial PPG has given the physician to analyze blood components noninvasively. A range of clinically relevant parameters like **heart rate**, respiratory rate, respiratory induced intensity variations (RIIV) ventilatory volumes; autonomic dysfunction can be obtained from the PPG signal. In this project we are going to measure the heart rate only.

PPG has several advantages:

1. It uses simple inexpensive optical devices for sensing that need little maintenance.
2. This device is compact and is portable.

Hence it can be used in all types of environments. The simplest PPG sensor consists of an infrared LED and a photodetector placed in a single plastic housing (fig.2.1). The sensor is put on the surface of the body by means of like headphone, ear buds, spectacles etc. The sensor can be either of transmitting type or reflecting type. The PPG sensor head can be modified by using an optical fiber to transmit and receive the light. With this modification, simultaneous measurements of PPG signal with MRI, ECG, EEG probes can be done without any electromagnetic interference problems.

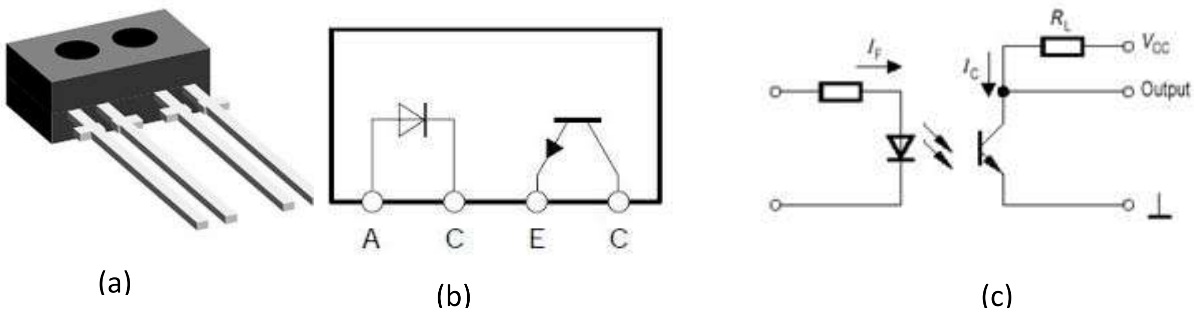


Figure 2.1: Reflective Optical Sensor with Transistor Output (TCRT1000). (a) TCRT1000 IC; (b) TCRT1000 symbol; (c) TCRT1000 circuit.

2.2. OPTIC SENSOR SYSTEM

A PPG optic sensor system consists of sensor head and related circuitry, signal conditioning circuit, and hardware interface. Instead of the sensor system, let us take a look at the optical properties of the skin wherein the basis of the principle of operation lies.

2.2.1. Optical properties of the skin

The interaction of electromagnetic radiation with the human tissue is well studied. It is seen that the skin acts as a scattering media in the wavelength region of 550-1100nm. The penetration of light increase with increase of wavelength. Blood being a mixture shows multiple absorption peaks pertaining to different constituents in the wavelength region of 300-500nm. No such specific absorption is seen in the IR region. The IR region is thus termed as Isobestic wavelength region for blood. Most PPG device used IR emitter in 800- 950nm region [2].

Figure 2.2 shows the different layers and vascular structure of the skin and their characteristics

1. ***Stratum corneam & Epidermis* (<200µm)**

This layer largely absorbs the light and does not modify the signal in any significant way. This has important implications. Skin color, pigmentations are due to this layer. Thus all these factors do not affect the PPG signal [2].

2. ***Dermis* (1-3mm)**

The dermis largely contains arterioles, veinules and capillaries. The bulk of the PPG signal is back scattered from this region [2].

3. ***Subcutaneous Tissue* (>3mm)**

This layer contains bigger arteries and veins. Since, much of the back-scattered light is from the dermis, and hence this layer has little effect on the PPG signal in reflection type [2].

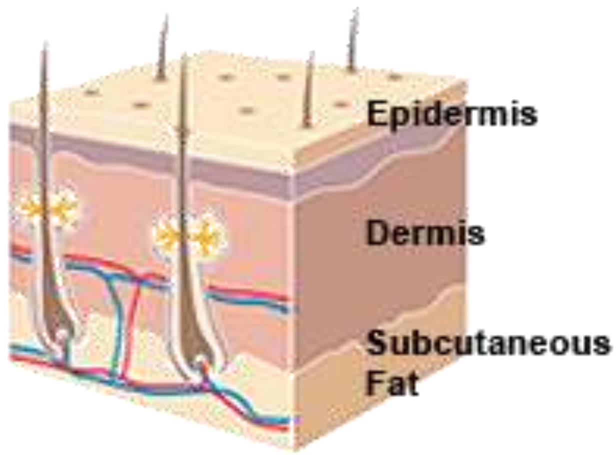


Figure 2.2: Skin / Vessel topography [3]

2.3. BASIC PRINCIPLE BEHIND PPG:

The basic principle behind the measurement of blood volumetric changes in the skin by means of PPG is the fact that hemoglobin in the blood absorbs infrared light many times stronger than the remaining skin tissues. It is known that in the range of invisible infrared light around 950nm (in this project we use TCRT1000 infrared sensor which wavelength is 950nm) there is a particularly favorable "measurement window" for optical sensing. Only a small proportion of the entering light is absorbed by the epidermis.

There is also a large difference between the reflection of the bloodless skin and the reflection from the vessels filled with blood. In bloodless skin 60% of the light is reflected back whereas in the skin with blood, 6% is reflected back (Fig 2.3) [2]. Since the full blood vessels reflected approximately 10 times less light than the skin tissue without blood, they appear as dark lines against a relatively light background.

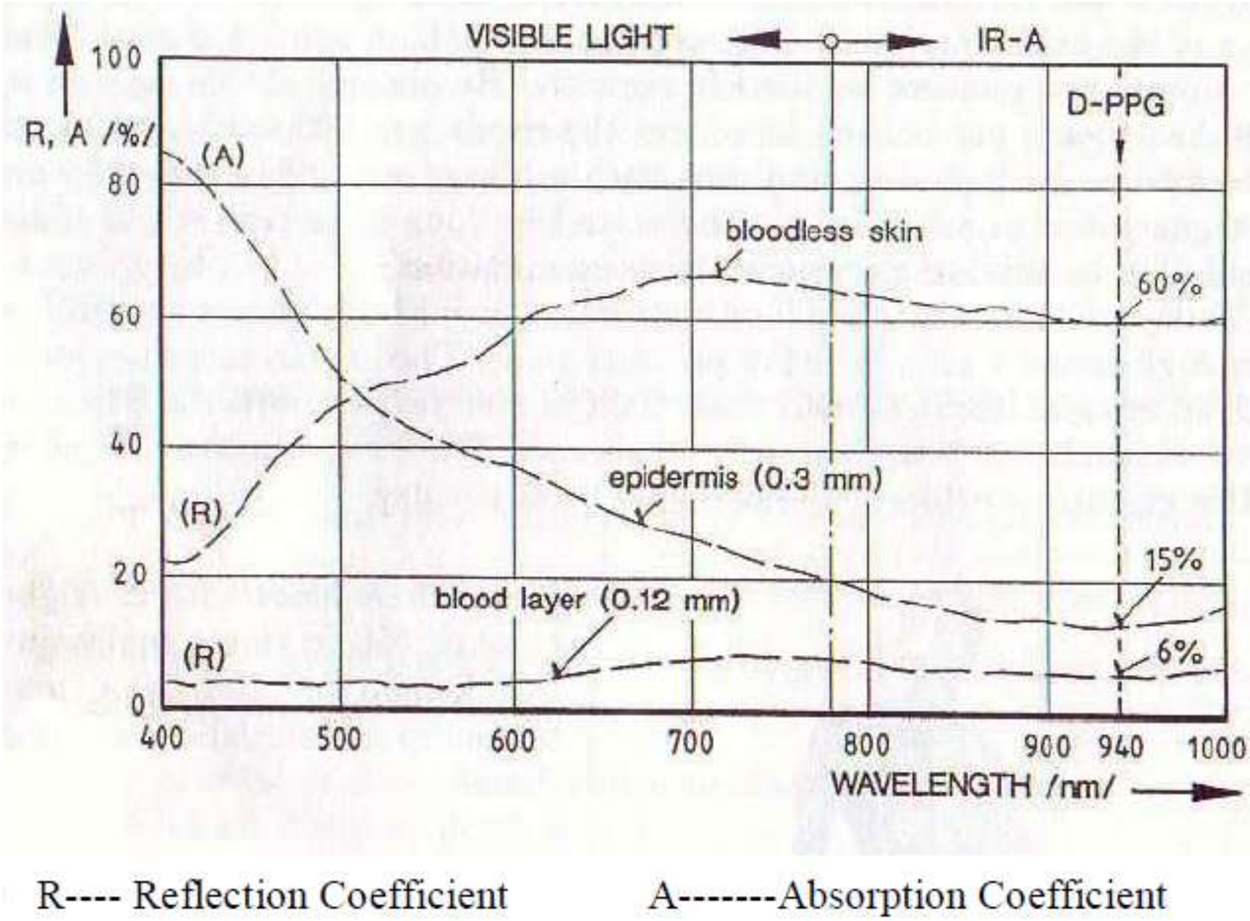


Figure 2.3: Optical Characteristics of Biological tissue in the visible and infrared range [2]

As the blood pressure in the skin vessels decreases, the surface area of the vessels will reduce. This increases the average reflection in the measuring window, so it will be recorded as an increase in the PPG signal. The optoelectronic measuring principle of the PPG thus depends on detecting the changes in reflection of the sub-epidermal layers of skin during and after a defined movement or occlusion routine, which causes variations in the volume of the vessel plexuses in the skin. As the optical radiation is introduced into tissue, part of the photons will be reflected directly by the skin surface, another fraction will be distributed in the tissue by absorption or scattering, while the remaining photons will travel into the tissue either straight through or with a number of collisions [2].

PPG uses low levels of infrared light to detect small changes in blood volume content in these regions. It gives a voltage signal, which is proportional to the amount of blood present in the blood vessels. This method gives only a relative measurement of the blood volumetric changes and it cannot quantify the amount of blood. However, it can reflect the dynamics of the blood volumetric changes exceedingly well.

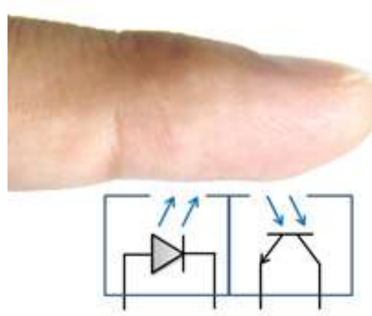
The PPG signal mainly consists of 3 components:

1. Arterial blood volumetric changes, which largely reflects the heart's activity.
2. Venous blood volume changes, which is a slow signal that has a modulatory effect on the PPG signal.
3. A DC component due to the optical property of the biological tissue

2.4. TYPE OF PPG SENSOR

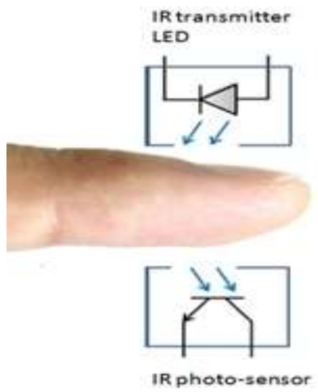
Transmittance and reflectance are two basic types of photoplethysmography. For the transmittance PPG, a light source is emitted into the tissue and a light detector is placed in the opposite side of the tissue to measure the resultant light. Because of the limited penetration depth of the light through organ tissue, the transmittance PPG is applicable to a restricted body part, such as the finger or the Ear lobe. However, in the reflectance PPG, the light source and the light detector are both placed on the same side of a body part. The light is emitted into the tissue and the reflected light is measured by the detector. As the light doesn't have to penetrate the body, the reflectance PPG can be applied to any parts of human body. In either case, the detected light reflected from or transmitted through the body part will fluctuate according to the pulsatile blood flow caused by the beating of the heart.

The following picture shows a basic reflectance PPG probe to extract the pulse signal from the fingertip. In this case the light source and the light detector are both placed on the same side of a body part. The light is emitted into the tissue and the reflected light is measured by the detector.



Finger 2.4: Photoplethysmography (reflectance approach) [5]

The following picture shows a basic transmittance PPG probe setup to extract the pulse signal from the fingertip. An IR LED and a photodetector are placed on two opposite sides and are facing each other. When a fingertip is plugged into the sensor, it is illuminated by the IR light coming from the LED. The photodetector transistor receives the transmitted light through the tissue on other side.



Finger 2.5: Photoplethysmography (transmittance approach) [5]

More or less light is transmitted depending on the tissue blood volume. Consequently, the transmitted light intensity varies with the pulsing of the blood with heart beat. A plot for this variation against time is referred to be a photoplethysmographic or PPG signal.

The PPG signal has two components, frequently referred to as AC and DC. The AC component is mainly caused by pulsatile changes in arterial blood volume, which is synchronous with the heart beat. So, the AC component can be used as a source of heart rate information. This AC component is superimposed onto a large DC component that relates to the tissues and to the average blood volume. The DC component must be removed to measure the AC waveform with a high signal-to-noise ratio. Since the useful AC signal is only a very small portion of the whole signal, an effective amplification circuit is also required to extract desired information from it.

The two maxima observed in the PPG are called Sytolic and Diastolic peaks, and they can provide valuable information about the cardiovascular system (this topic is outside the scope of this article). The time duration between two consecutive Systolic peaks gives the instantaneous heart rate.

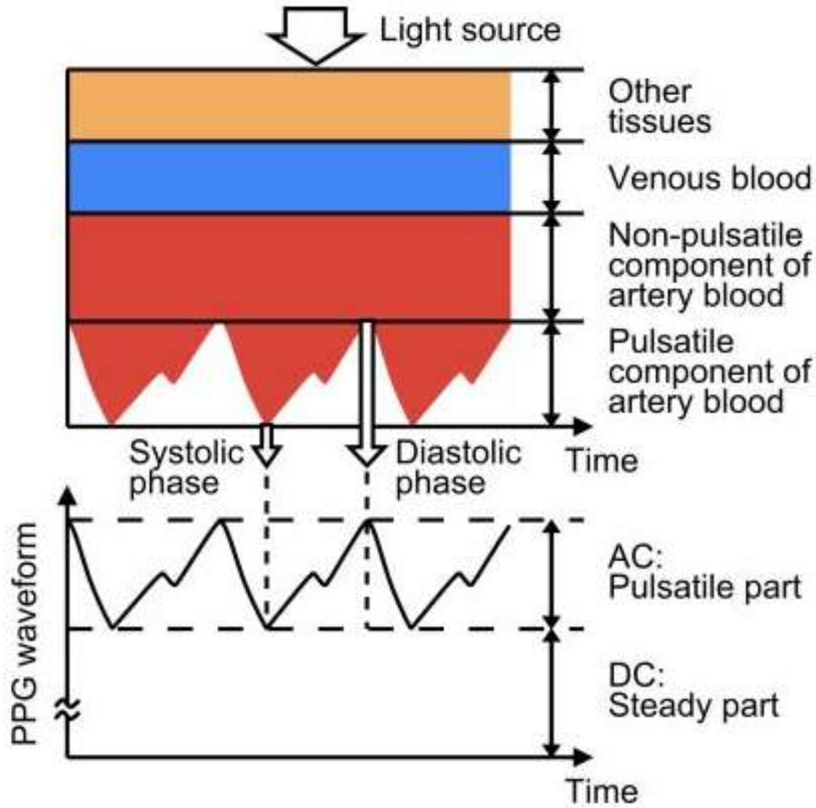


Figure 2.6: PPG signal with AC and DC components [5]

2.5. HEART RATE AND HEART RATE VARIABILITY (HRV)

Most people are familiar with "Heart Rate (HR)" expressed in beats per minute (BPM). Heart Rate refers to the absolute number of heart beats occurring during a 60 second period. But Heart rate variability (HRV) is the physiological phenomenon of variation in the time interval between heartbeats. In other word Heart rate variability (HRV) refers to the natural variation in heart rate that occurs over a period of time. It is measured by the variation in the beat-to-beat interval. Using LabView oscilloscope we find the time period of some interval PPG signal from peak to peak and calculate the heart rate of each beat as we can see on the figure 2.7 below. The time per division of the oscilloscope is setting 200ms. Using time domain analysis we can determine the heart rate variability using PPG graph shown on figure 2.7 below.

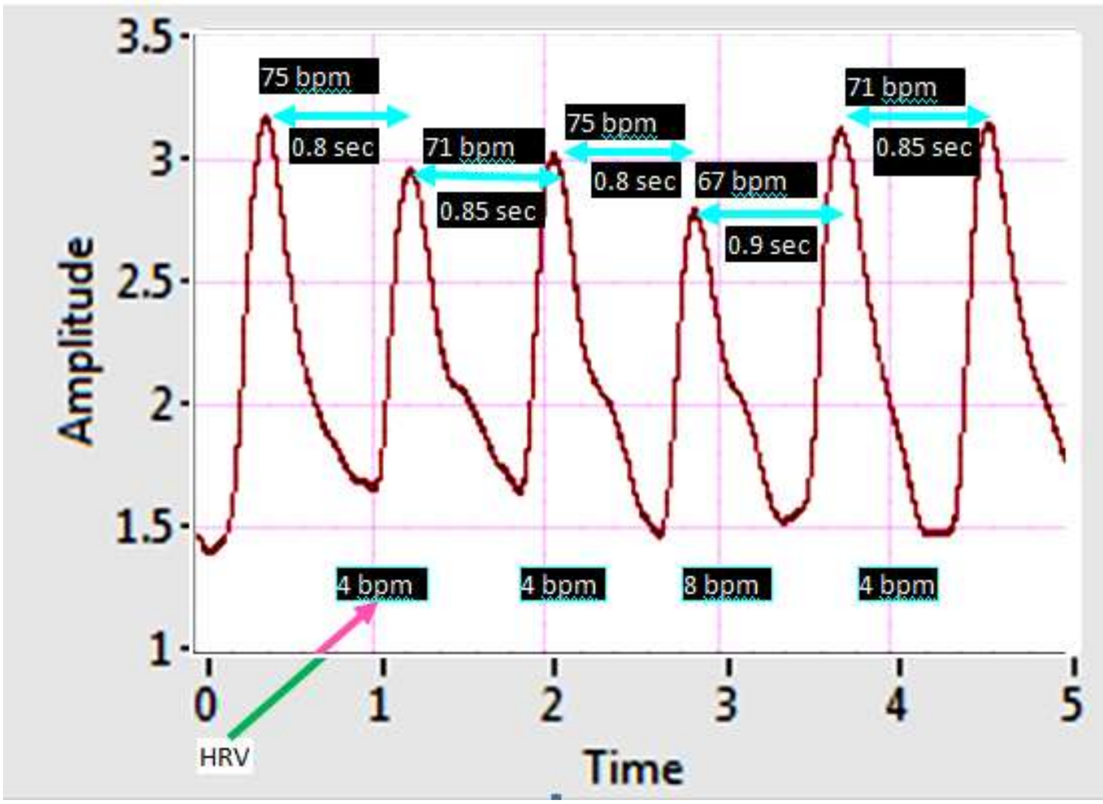


Figure 2.7: heart rate variability from PPG signal

Or using actual measurement we can find heart rate variability from figure 2.8 shown below.

For our purposes, (average) heart rate variability is expressed by the following formula:

HRV(av)= [((peak high rate 1 - peak low rate 1)+…..(peak high rate n -peak low rate n))/n]

$= HVR_1 + HVR_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + HVR_n$

To make this clear, figure 2.8 below presents the measurement of 5 complete heart rate variability cycles, numbered 1-5 from left to right. The X axis equals time and the Y axis equals heartbeat rate in beats per minute (BPM). The top peaks of the blue line represent the highest heartbeat rate in beats per minute (BPM) on a per cycle basis. Similarly, the bottom "valleys" represent the lowest heartbeat rate in beats per minute (BPM).

Take five beat values: 75, 71, 75, 67 and 71then plot the graph using Microsoft Excel 2007, we got heart Rate vs time graph shown below.

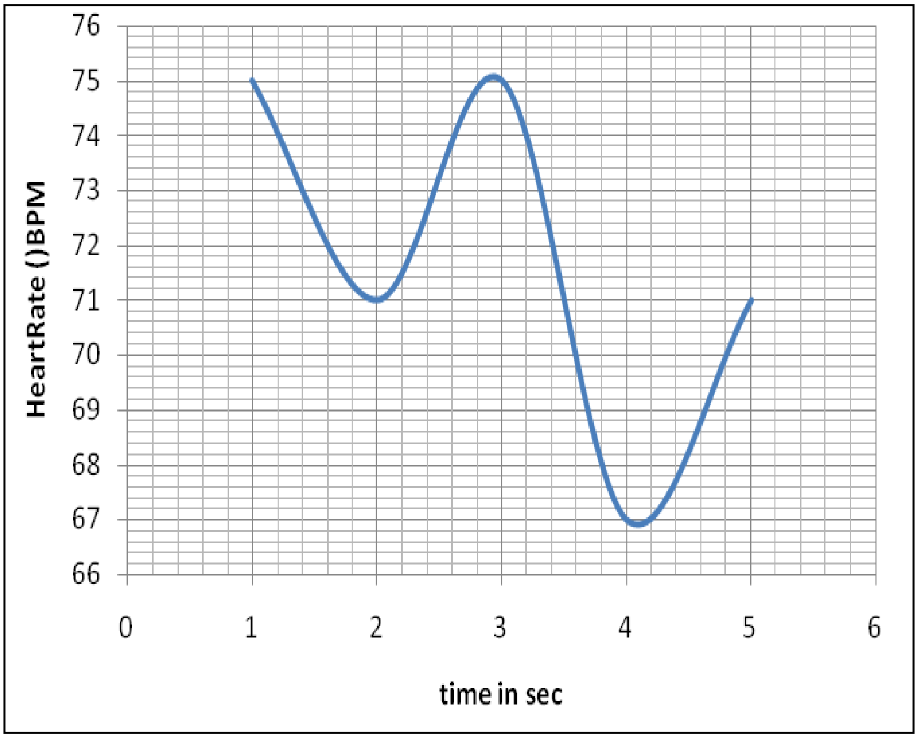


Figure 2.8: HRV with actual measurement

From the figure we got 4 beat to beat values:

HRV_1 = 75 bpm – 71 bpm = 4 bpm

HVR_2 = 75 bpm – 71 bpm = 4 bpm

HRV_3 =75 bpm – 67 bpm = 8 bpm

HRV_4= 71 bpm - 67 bpm =4 bpm

Then

$HRV_{(avg)}$ = 5 BPM

All these calculation is done through Arduino microcontroller and store it in a serial EEPROM. **.**

At each variation within the number of heart beats in a minute, three bytes representing the new number and time corresponding are stored in the memory. Final calculate the average time period of the signal to find the average Heart Rate in one minute. This value is displayed on android phone through Bluetooth communication.

CHAPTER 3

DESIGN AND DEVELOPMENT OF HARDEWARE SYSTEM

3.1. PROPOSED HEADPHONE BASED HR AND ARV MONOTORING SYSTEM

Figure 3.1: Proposed system component placement on the Headphone

A pictorial representations of the monitoring system given in figure 3.1. The Battery, Sensor, signal conditioning circuit, Bluetooth, arduino pro-mini and DC-DC step-up converter are integrated as illustrated in the diagram. Developments of the individual circuits are discussed below.

3.2. THE BLOCK DIAGRAM OF THE SYSTEM

The general block diagram of Headphone based heart Rate and Heart Rate Variability monitoring using reflective photoplethysmography (PPG) technique is shown as below in figure 3.1 gives the hardware block of the proposed system. In this project the Liquid Crystal oscillator is an optional display system that is if someone is interested to use the LCD display instead of Android device display.

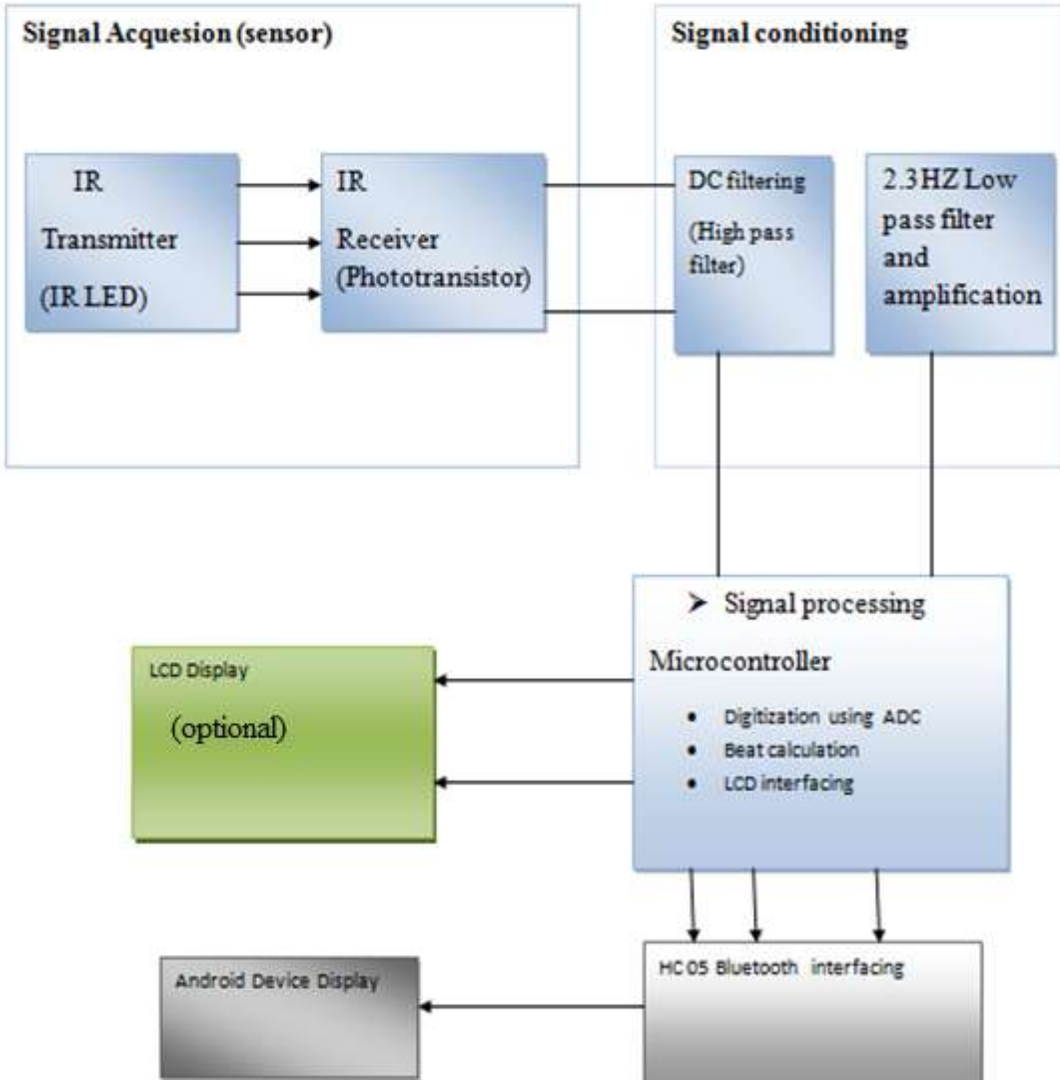


Figure 3.2: Block diagram of hardware system

3.2.1. SIGNAL ACQUISITION

This block contains Reflective Optical Sensor with Transistor Output that is IR transmitter (IR LED) and IR receiver (IR phototransistor). The light source (IR LED) and the light detector (IR phototransistor) are both placed on the same side of a body part. The light is emitted into the tissue and the reflected light is measured by the detector. The output from IR receiver (phototransistor) is a periodic physiological waveform attributed to small variations in the reflected IR light which is caused by the pulsatile tissue blood volume inside the tissue. The waveform is, therefore, synchronous with the heart beat.

3.2.2. SIGNAL CONDITIONING

The PPG signal consists of a large DC component, which is attributed to the total blood volume of the examined tissue, and a pulsatile (AC) component, which is synchronous to the pumping action of the heart. The AC component, which carries vital information including the heart rate, is much smaller in magnitude than the DC component and the PPG signal coming from the phototransistor is weak and noisy. So we need an amplifier and filter circuits to boost and clean the signal to obtain photoplethysmograph (PPG) signal.

3.2.3. INFRARED TRANSMITTER (IR LED)

Infrared Transmitter is a light emitting diode (LED) which emits infrared light, means it emits light in the range of Infrared frequency. We cannot see Infrared light through our eyes; they are invisible to human eyes. The wavelength of Infrared (700nm - mm) is just beyond the visible light.

When the IR transmitter emits radiation, it reaches the object and some of the radiation reflects back to the IR receiver. Based on the intensity of the reception by the IR receiver, the output of the sensor is defined.

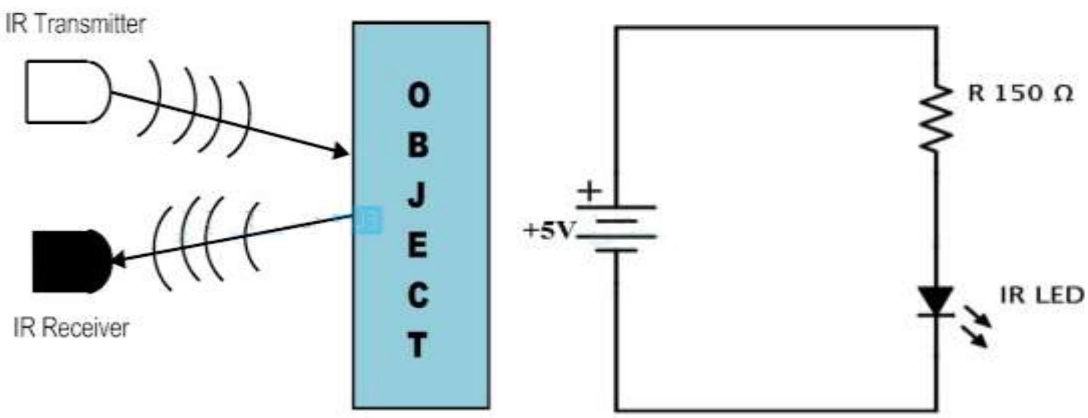


Figure 3.3: Active infrared sensor elements: infrared source and infrared detector

When a forward biasing voltage is applied to the input terminals of the LED, an input current limited by the series resistor will follow in the LED circuit. The current produces the infrared light emission at about 950nm that affect the photo-sensitive detector. The value of limiting resistor is in the order of few hundreds of ohms. In this project IR transmitter and receiver which part number: TCRT1000 is used for the application.

3.2.4. INFRARED DETECTOR (PHOTOTRANSISTOR)

A Phototransistor is an electronic switching and current amplification component which relies on exposure to light to operate. When light falls on the junction, reverse current flows which is proportional to the luminance. Phototransistors are used extensively to detect light pulses and convert them into digital electrical signals. These are operated by light rather than electric current. Providing large amount of gain, low cost and these phototransistors might be used in numerous applications [4].

It is capable of converting light energy into electric energy. Phototransistors are able to produce both current and voltage. Phototransistors are transistors with the base terminal exposed. Instead of sending current into the base, the photons from striking light activate the transistor. This is because a phototransistor is made of a bipolar semiconductor and focuses the energy that is passed through it. These are activated by light particles and are used in virtually all electronic devices that depend on light in some way. All silicon photo sensors (phototransistors) respond to the entire visible radiation range as well as to infrared [4].

A phototransistor is nothing but an ordinary bi-poplar transistor in which the base region is exposed to the illumination. It is available in both the P-N-P and N-P-N types having different configurations like common emitter, common collector and common base. Common emitter and N-P-N configuration is used in this project. It can also work while base is made open. Compared to the conventional transistor it has more base and collector areas. Ancient photo transistors used single semiconductor materials like silicon and germanium but now a day's modern components uses materials like gallium and arsenide for high efficiency levels. The base is the lead responsible for activating the transistor. It is the gate controller device for the larger electrical supply. The collector is the positive lead and the larger electrical supply. The emitter is the negative lead and the outlet for the larger electrical supply.

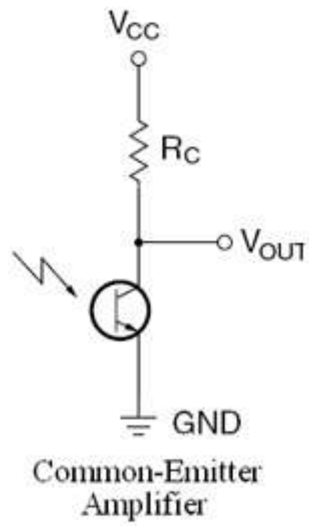


Figure 3.4: Common emitter type phototransistor

With no light falling on the device there will be a small current flow due to thermally generated hole-electron pairs and the output voltage from the circuit will be slightly less than the supply value due to the voltage drop across the load resistor R. With light falling on the collector-base junction the current flow increases. With the base connection open circuit, the collector-base current must flow in the base-emitter circuit and hence the current flowing is amplified by normal transistor action. Collector base junction is very sensitive to light .Its working condition depends upon intensity of light. The base current from the incident photons is amplified by the gain of the transistor, resulting in current gains that range from hundreds to several thousands. A phototransistor is 50 to 100 times more sensitive than a photodiode with a lower level of noise.

Why Photo transistors are used instead of photodiode?

Because Phototransistors have several important advantages that separate them from other optical sensor some of them are mentioned below

- Phototransistors produce a higher current than photodiodes.
- Phototransistors are relatively inexpensive, simple, and small enough to fit several of them onto a single integrated chip.
- Phototransistors are very fast and are capable of providing nearly instantaneous output.
- Phototransistors produce a voltage, that photo-resistors cannot do so.

3.3. OUTPUT PROCESSING AND DISPLAY

3.3.1. Arduino pro-mini

Arduino pro-mini board is heart of the project and is responsible for all the major digitalization of PPG signal and beat rate calculation in this project. Due to its robustness and open source nature, it is interfaced with the PPG sensor and the Bluetooth module easily. The Arduino pro-mini board has a microcontroller based on ATmega328P.This board provides the services of serial communication for displaying the received data on the android device and provides an Integrated Development Environment for easy programming.

Figure 3.5: Arduino pro-mini Board

3.3.2. LCD (Liquid Crystal Display)

LCD (Liquid Crystal Display) screen is an electronic display module. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on.16 x 2 LCD is used here.16x2 means it can display 16 characters per line and there are 2 such lines.

Figure 3.6: Output on LCD

3.3.3. **HC-05 Bluetooth Module**

HC-05 as shown in Figure 3.7 is a Bluetooth module which operates on the principle of Serial Port Protocol (SPP). This module is specifically designed for wireless serial communication. This module is equipped with Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It makes use of CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). The Bluetooth module is used for its low cost, low consumption of power and high range that enables the user to access the weather station from a considerable distance. The Bluetooth module has a sensitivity of -80dBm.It makes use of UART interface whose baud rate can be programmed. Typically the baud rate used is 38400 and the data packet usually involves 8 bit of data, 1 stop and no parity bits. These Bluetooth modules have two modes: master and slaver device. Those devices with even number (HC-04) can be configured as master or slaver when it is out of factory and can't be changed to the other mode. However, for the device with odd number like HC-05, the user can configure the mode as master or slave using AT commands. The Bluetooth module used in the project is HC-05 which operates in the slave mode. HC-05 is a 6 pin IC where the TX and RX pin is connected to the RX and TX pin of the Arduino board respectively. We can use the voltage supply required for this HC-05 from the Arduino potential 3.3 V for proper transmission and reception between the Arduino and the Bluetooth Module. We have to make sure that the baud rate of the Bluetooth module is synchronised with that of the Arduino so that there is no loss of data and proper communication is achieved.

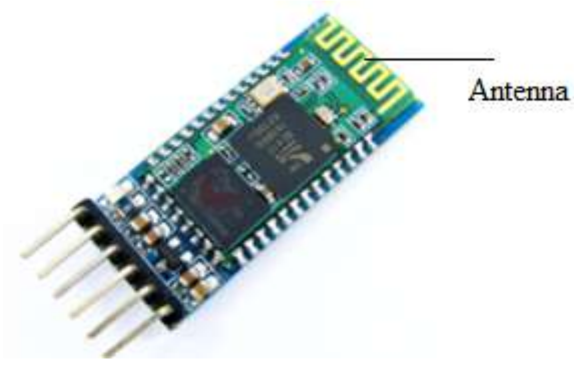


Figure 3.7: HC-05 Bluetooth Module

Specifications:

- Bluetooth protocal: Bluetooth Specification v2.0+EDR(Enhanced Data Rate)
- Frequency: 2.4 GHz radio transceiver and baseband
- Modulation: GFSK(Gaussian Frequency Shift Keying)
- Sensitivity: ≤-84 dBm at 0.1% BER
- Speed: Asynchronous: 2.1 Mbps(Max) / 160 kbps, Synchronous: 1 Mbps/1 Mbps
- Power supply: +3.3 VDC 50 mA
- Working temperature: -20 ~ +75 Centigrade
- Dimensions: 15.2 x 35.7 x 5.6 mm

3.3.4. Development Of The Android Interface

The android interface is used in this project to showcase the data obtained in the form of beat per minute. MIT APP Inventor is android application that used for Bluetooth communication. It enables the connection of Android devices with any Bluetooth device which is associated with Serial Port Profile. This allows easy exchange of data between the two systems in both master and slave mode. In this project, the data in the form of beat rate per minute is displayed on the Android mobile phone and Android tablet.

The main advantage of using this application is to provide a user friendly interface which avoids any ambiguities for the user as shown in Figure 3.8. The data sent to the android device through Bluetooth and received the beat rate using this android application.

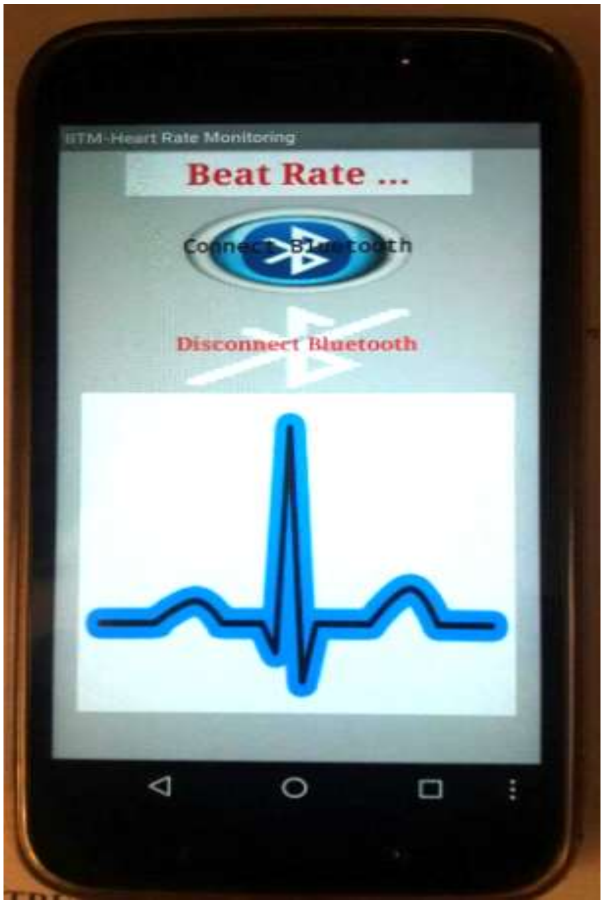


Figure 3.8: Beat per minute display application screen

3.3.5. ARDUINO IDE

It provides an integrated development environment for programming of arduino pro-mini boards. A program or a code written for arduino is called a SKETCH. Arduino sketch window looks as the one shown below:

Figure 3.9: Arduino Ide sketch window

3.4. CIRCUIT DIAGRAM OF THE SENSOR AND SIGNAL CONDITIONING

3.4.1. Infrared Sensor

The sensor used in this project is TCRT1000, which is a reflective optical sensor with both the infrared light emitter and phototransistor placed side by side and are enclosed inside a leaded package so that there is minimum effect of surrounding visible light. The circuit diagram below shows the external biasing circuit for the TCRT1000 sensor. Pulling the Enable pin high will turn the IR emitter LED on and activate the sensor. A sensor, placed over the surface of a body, will act as a reflector of the incident light. The amount of light reflected back from the surface of the body is monitored by the phototransistor. The phototransistor output (V_{SENSOR}) contains the PPG signal that goes to a two-stage filter and amplifier circuit for further processing.

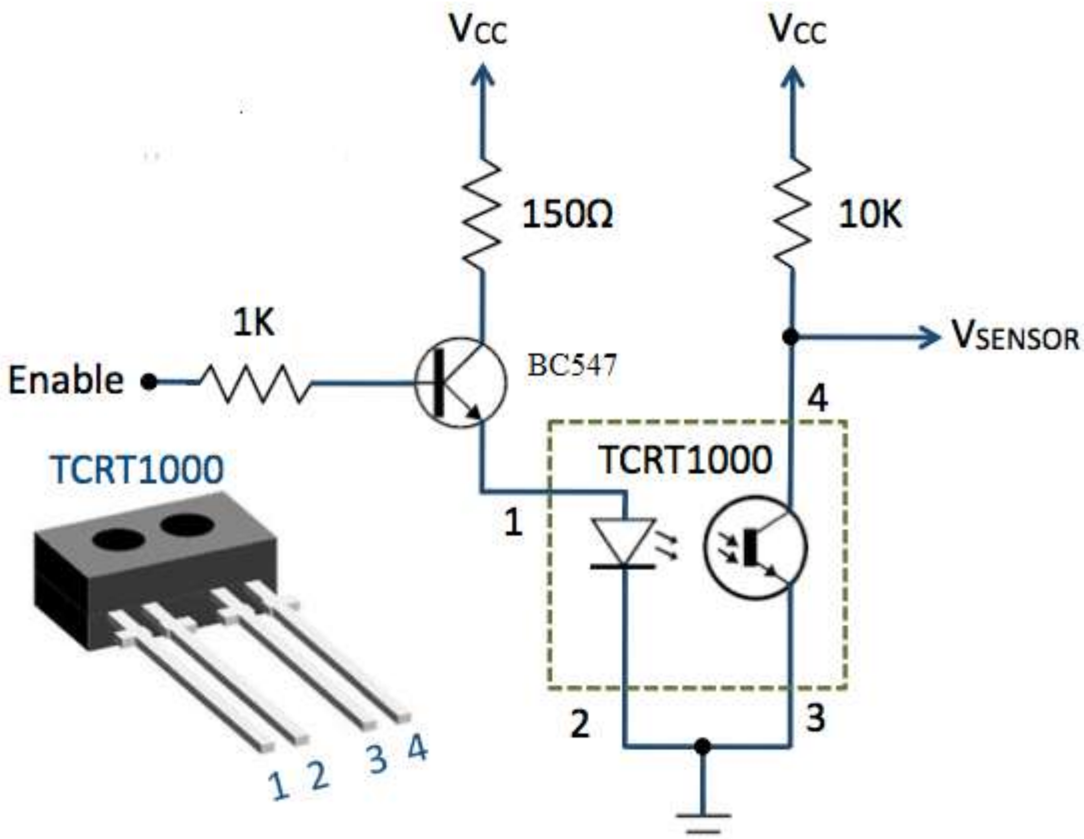


Figure 3.10: TCRT1000 used for sensing pulse from body surface

The output (V_{SENSOR}) from the sensor is a periodic physiological waveform attributed to small variations in the reflected IR light which is caused by the pulsatile tissue blood volume inside the tissue. The waveform is, therefore, synchronous with the heart beat. The PPG signal coming from the photodetector is weak and noisy. So we need an amplifier and filter circuits to boost and clean the signal. In Stage I signal conditioning circuit, the signal is first passed through a passive (RC) high-pass filter (HPF) to block the DC component of the PPG signal.

The specification of the components used in the circuit shown in Figure 3.9 is

a) Reflective Optical Sensor with Transistor Output-TCRT1000

The TCRT1000 is reflective sensors which include an infrared emitter and phototransistor in a leaded package which blocks visible light.

- Detector type: phototransistor
- Dimensions (L x W x H in mm): 7 x 4 x 2.5
- Peak operating distance: 1 mm
- Operating range within > 20 % relative collector current: 0.2 mm to 4 mm
- Emitter wavelength: 950 nm
- Input(Emitter) forward current:50 mA
- Output(Collector) current:50 mA
- Total power dissipation:200 mW

b) Transistor-BC547

- Collector Current (I_C) :100 mA
- Collector Power Dissipation(P_C) : 500 mW
- Collector-Emitter Voltage(V_{CEO}) : 45 V

3.4.1.1. Sensor output signal

The output voltage from phototransistor consists of the PPG signal and slow varying high DC voltage. The output wave form of the sensor shown below at different surface of the body.

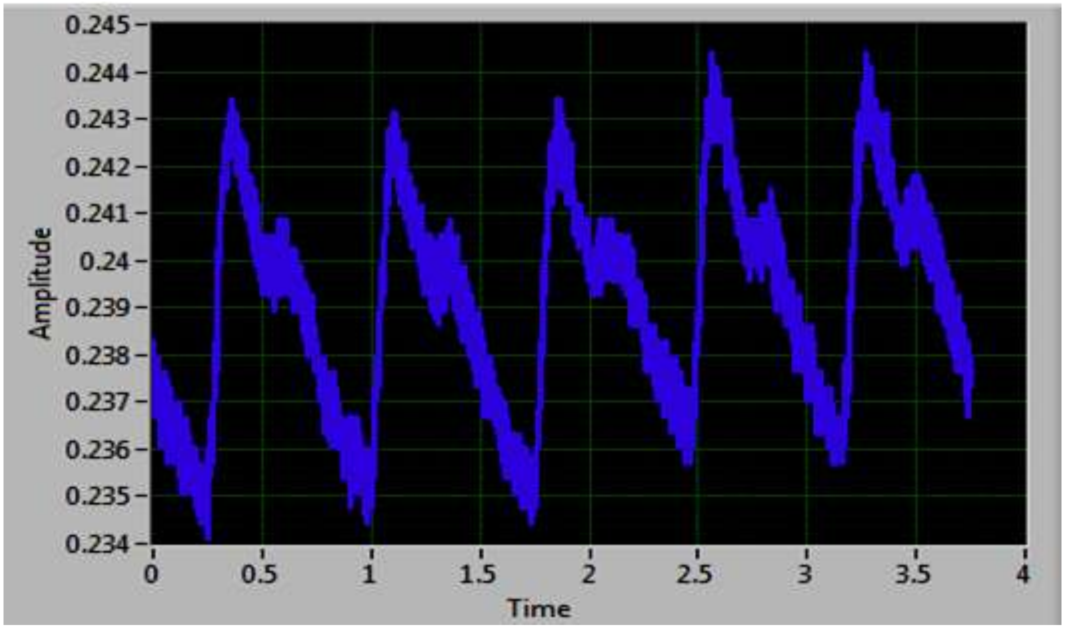


Figure 3.11: Sensor output signal from finger tip (before filtering and processing)

The PPG signal from the finger tip has low slow varying DC voltage and relatively high AC signal compare to other surface of the body as show figure 3.10 above.

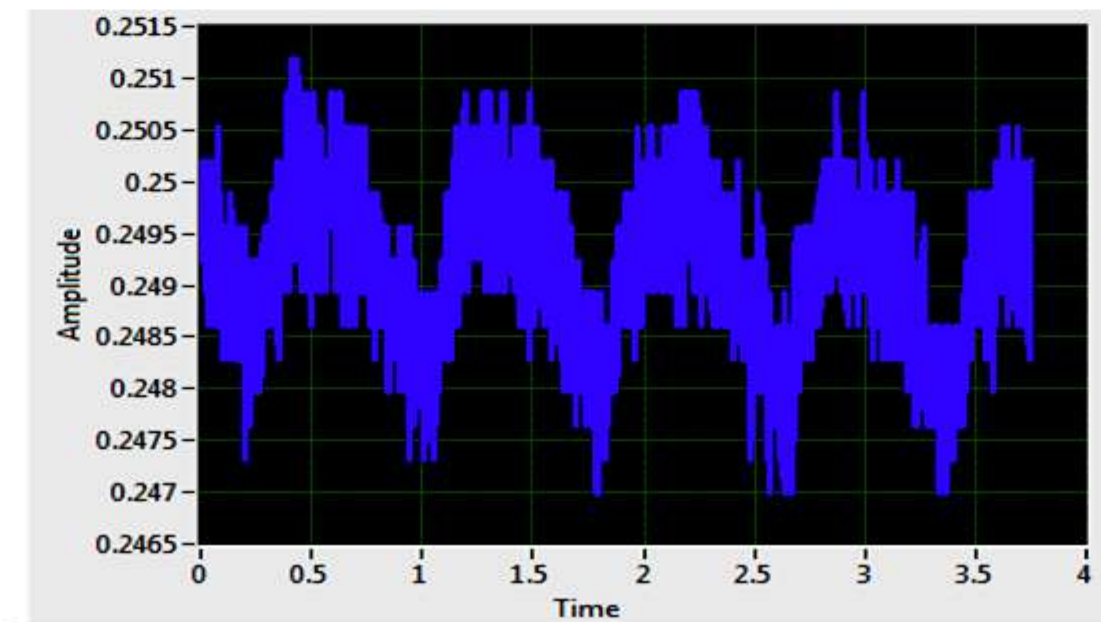


Figure 3.12: Sensor output signal from near to Ear surface (before filtering and processing)

The output signal from the sensor near to Ear as we can see from the above figure 3.11 the slow varying DC voltage is higher and AC signal is low compare to the sensor place on the finger tip.

.

3.4.2. Signal Conditioning Circuit

The reflected IR signal detected by the phototransistor is fed to a signal conditioning circuit that filters the unwanted signals and boost the desired pulse signal.

3.4.2.1. High Pass Filter

A high pass filter, or HPF, is a Linear Time Invariant Filter that passes high frequencies but attenuates frequencies lower than the filter's cut off frequency. The actual amount of attenuation for each frequency is a design parameter of the filter. It is sometimes called a low cut filter or bass-cut filter. This circuit is the first stage of the signal conditioning which will suppress the large DC component from sensor output to produce the required information. The cut-off frequency of the HPF is set to **0.5 Hz.**

High pass filter circuit design

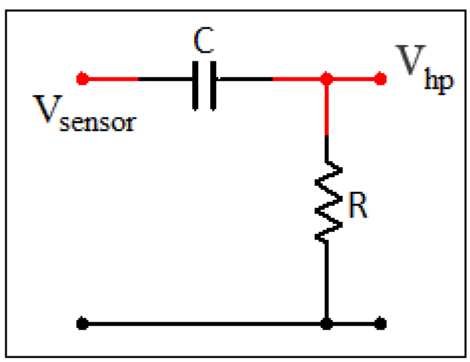


Figure 3.13: passive high pass filter

Choose C = 4.7 µF, f_0 = 0.5 Hz

$$f_0 = \frac{1}{2\pi RC}$$

From this

$$R = \frac{1}{2\pi f_0 C} = \frac{1}{2\pi x 0.5 x 4.7 x 10^{-6}} = 67.7k\Omega \approx 68k\Omega$$

3.4.2.2. Butterworth active low pass filter

Butterworth filter is a type of filter whose frequency response is flat over the passband region. Low-pass filter (LPF) provides a constant output from DC up to a cutoff frequency f_0 and attenuating (reducing the amplitude of) signals with frequencies higher than the cut-off frequency. The actual amount of attenuation for each frequency varies from filter to filter. The first order low-pass filter has a practical slope of -20 dB/decade. The low-pass filter has a constant gain A_f from 0 to high cutoff frequency f_0. At f_0 the gain is $0.707A_f$ and after f_0 it decreases at a constant rate of 20dB/decade. The frequency f = f_0 is called the high cutoff frequency because the gain of the filter at this frequency is down by 3 dB (=20 log $_{(10)}$ 0.707) from 0 Hz. The low pass filter is used to remove the noise including 60 Hz (50 Hz in some countries) mains interference, while amplifying the low amplitude pulse signal (AC component) 2063 times. The cut off here is set to 2.33 Hz.

Circuit diagram

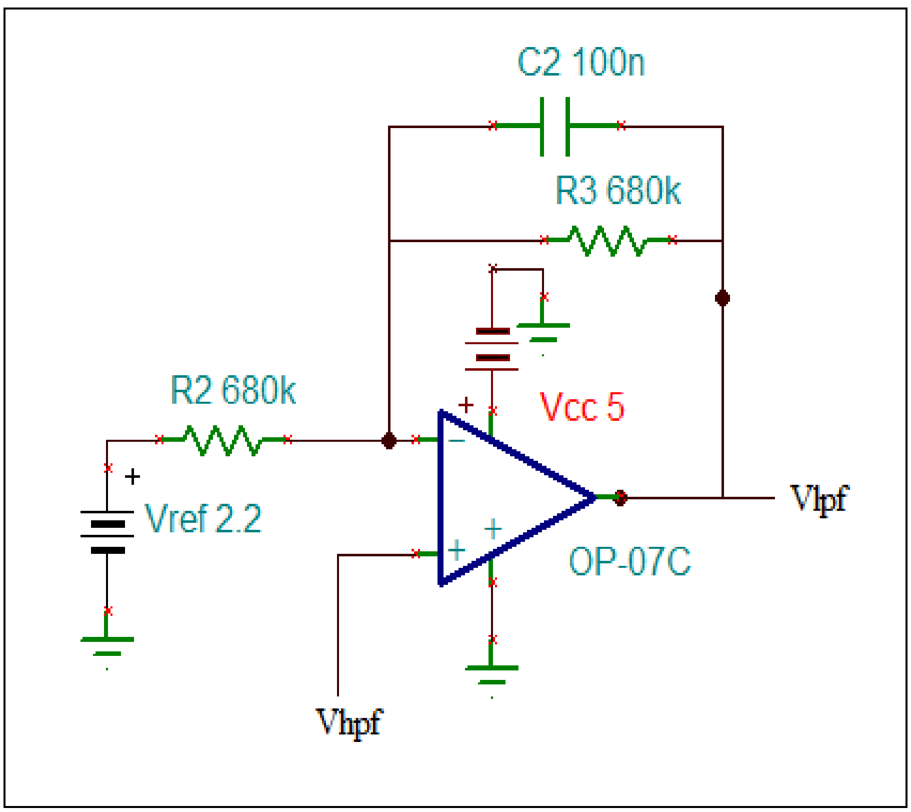


Figure 3.14: active low pass filter

Feature of OP AMP (OP07) used for signal conditioning circuit

- Low noise
- No External Components Required
- Replace Chopper Amplifiers at a Lower Cost
- Wide Supply-Voltage Range: ±3 V to ±18 V
- Power dissipation: 4mW to 8mW.

Choose C = 100 nF, f_0 = 2.33 Hz and R_1 = 6.8 kΩ

$$f_o = \frac{1}{2\pi R_2}$$

From this

$$R_2 = \frac{1}{2\pi f_o C} = \frac{1}{2\pi \times 2.33 \times 100 \times 1^{-9}} = 683K\Omega \approx 680K\Omega$$

In the above circuit the cutoff frequency is decided by the resistor R2 and capacitor C. We can choose any desired value to fix the cutoff frequency. In the above circuit we fix the cutoff frequency to be approximately 2.33 KHz this related to the maximum heart rate of 140 bpm so we used the resistor R_2 of value 680KΩ and capacitor of value 100nF. You can change it if you want to by using the above cutoff frequency formula.

Resistors R_1 and R_2 determine the gain of the filter. The voltage gain below the high cutoff frequency is called the pass band gain. It is given by the formula:

$$G_1 = 1 + \frac{R_2}{R_1} = 1 + \frac{680K}{6.8K} = 1 + 100 = 101$$

3.4.2.3. First stage signal conditioning circuit

The following circuit diagram describes the first stage of the signal conditioning which will suppress the large DC component and boost the weak pulsatile AC component, which carries the required information.

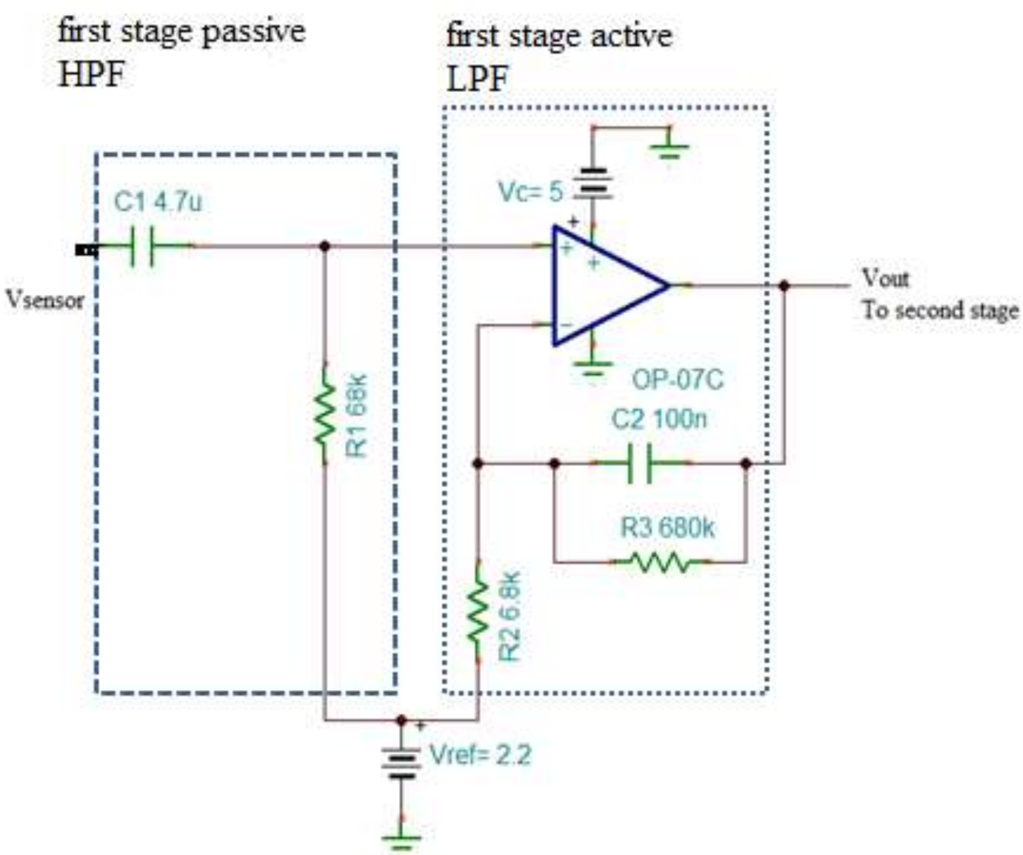


Figure 3.15: First stage of signal conditioning circuit

In the circuit shown above, the sensor output is first passed through a RC high-pass filter (HPF) to get rid of the DC component. The cut-off frequency of the HPF is set to 0.5 Hz. Next stage is an active low-pass filter (LPF) that is made of an Op-Amp circuit. The gain and the cut-off frequency of the LPF are set to 101 and 2.34 Hz, respectively. Thus the combination of the HPF and LPF helps to remove unwanted DC signal and high frequency noise including 60 Hz (50 Hz in some countries) mains interference, while amplifying the low amplitude pulse signal (AC component) 101 times.

The PPG voltage from the first stage signal conditioning circuit has low slow varying DC voltage and high AC signal as shown on Figure 3.16.

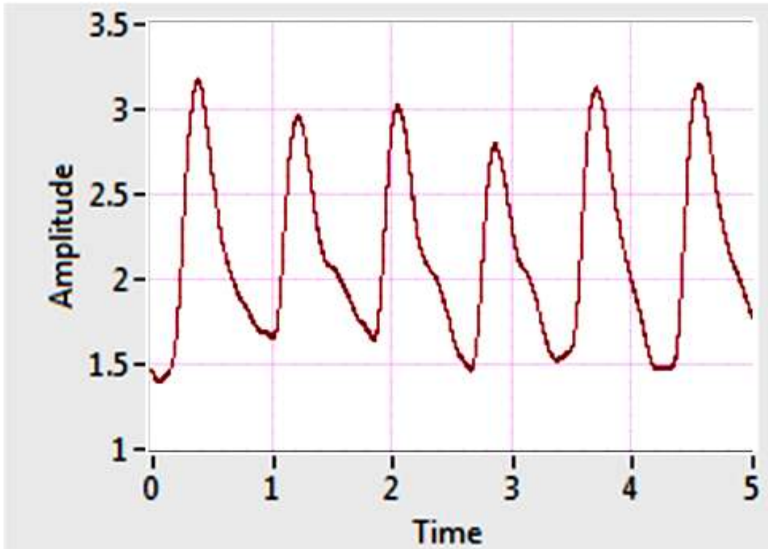


Figure 3.16: PPG signal from First stage of signal conditioning

3.4.2.4. Second Stage Signal Conditioning Circuit

The output from the first signal conditioning stage goes to the second stage HPF/LPF combination for further filtering and amplification shown figure 3.18. So, the total voltage gain achieved from the two cascaded stages is 101 x 20.4 = 2063.28. The output from the active Low Pass Filter now goes to Second Stage high pass circuit, which is basically a replica of the First Stage circuit. Note that the amplitude of the signal going to the second stage is controlled by gain G_1. The Op-amp used in this project is OP07, which is a Quad-Op amp device and provides rail-to-rail output swing.

The second stage also consists of similar HPF and different gain from the first stage LPF circuits. The two-step amplified and filtered signal is now fed to a second Op-amp, which is configured as a non-inverting buffer with G_2 gain. The output of the second stage provides the required analog PPG signal. The Gain G2 can be used to control the amplitude of the PPG signal appearing at the output of the second stage.

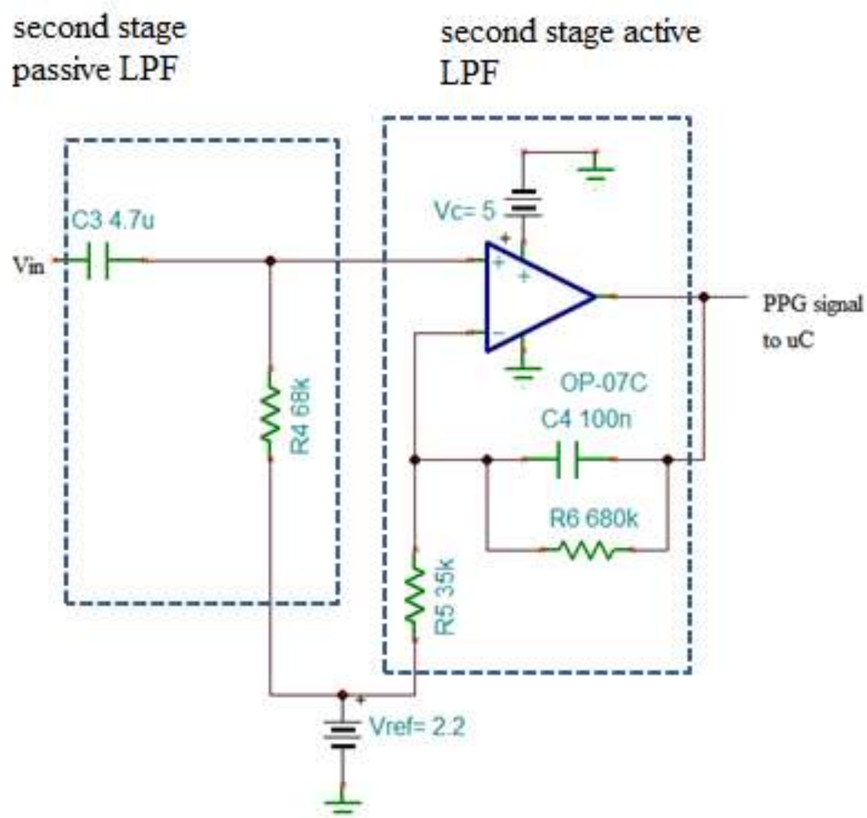


Figure 3.17: Second stage of signal conditioning circuit

Resistors R_5 and R_6 determine the gain of the second stage filter. The voltage gain of non inverting op amp is given by the formula:

$$G_1 = 1 + \frac{R_6}{R_5} = 1 + \frac{680K}{35K} = 1 + 19.4 = 20.4$$

So, the total voltage gain achieved from the two cascaded stages is:

101*20.4 = 2063.28.

The frequency (f) of these pulses is related to the heart rate (BPM) as,

Beats per minute (BPM) = 60*f

3.4.3. Zener Reference Voltage(MMSZ4680T1G)

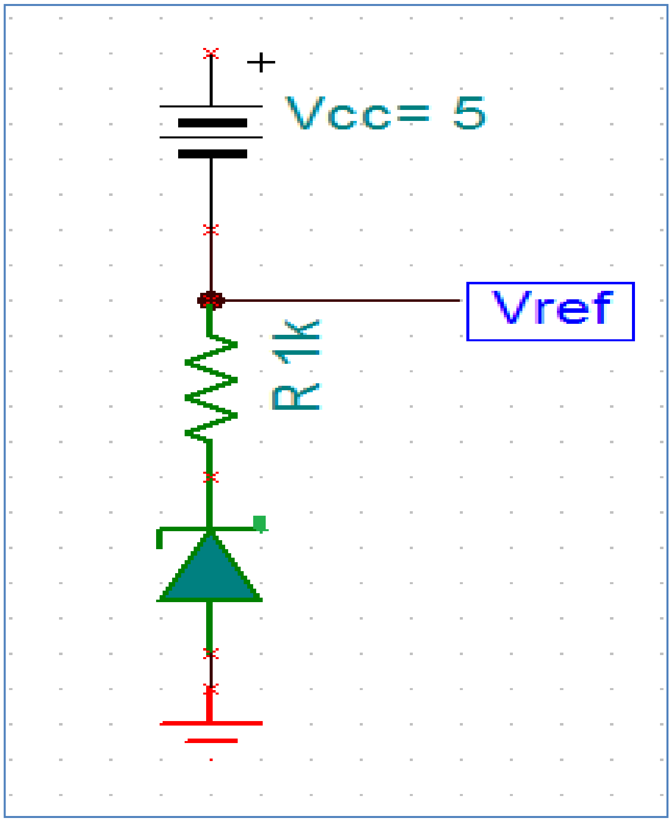


Figure 3.18: MMSZ4680T1G Zener diode

In order to achieve a full swing of the PPG signal at the output, the negative input of the Opamp is tied to a reference voltage (Vref) of 2.2V. The Vref is generated using a Zener diode. In this project we use MMSZ4680T1G Zener diode. This reference voltage used for enabling the transistor to turn the IR emitter LED On and activate the sensor.

Features of MMSZ4680T1G

- Power dissipation: 500mW
- Zener Reverse Voltage Range :1.8 V to 43 V
- Zener voltage: 2.09 to 2.31V normal 2.2V
- These Devices are Lead Free

3.4.4. Full schematic PPG signal acquisition

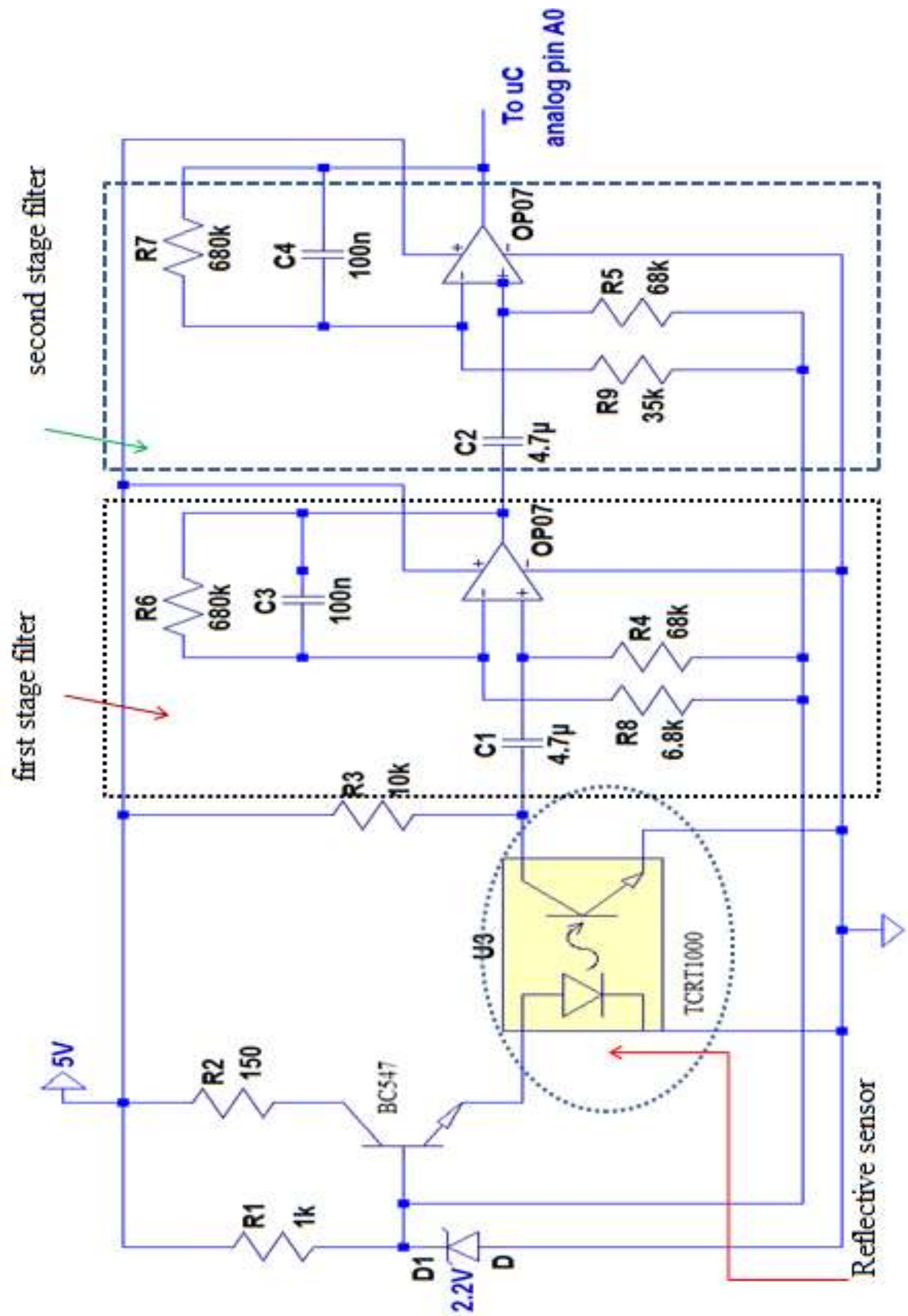


Figure 3.19: Full schematic PPG signal acquisition

3.5. PROTOTYPE UNIT OF THE PROPOSED SYSTEM

The figure 3.20 is represents the realization of the circuit diagram discoursed in figure 3.29 into hardware circuit using breadboard and the NI ELVIS II. Currently the power to the unit is used to power only -5 V and 5V is supplied from NI ELVIS II. The waveform is displayed by the laptop using LabVIEW oscilloscope. The hardware circuit draws a maximum current of 160mA and the power consumed by the circuit is around 1.2W excluding the current drawn and the power consumed by the Bluetooth and Arduino pro mini LEDs. The batteries can provide power to the circuit for short period of time because of the high power consumption on Bluetooth and arduino pro mini device. The figure 3.20 shows the integrated setup for heart rate monitoring system.

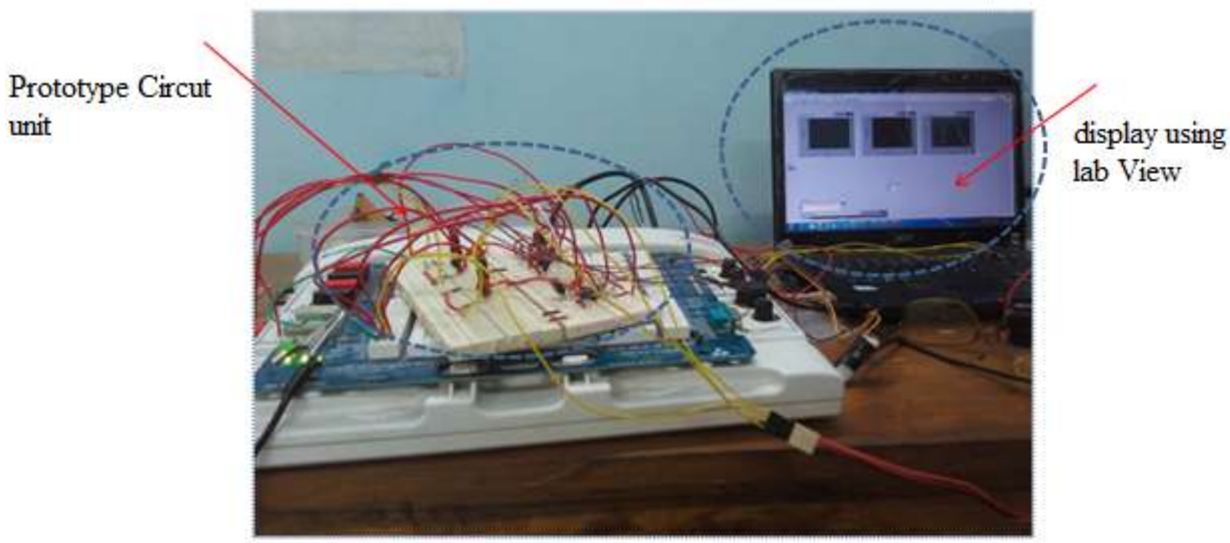


Figure 3.20: Prototype hardware setup on NI ELVIS board

After we checked the output PPG signal of the prototype as shown on Figure 3.20 we have translated from breadboard to PCB as shown on Figure 3.21 for the purpose of portability during testing in the car.

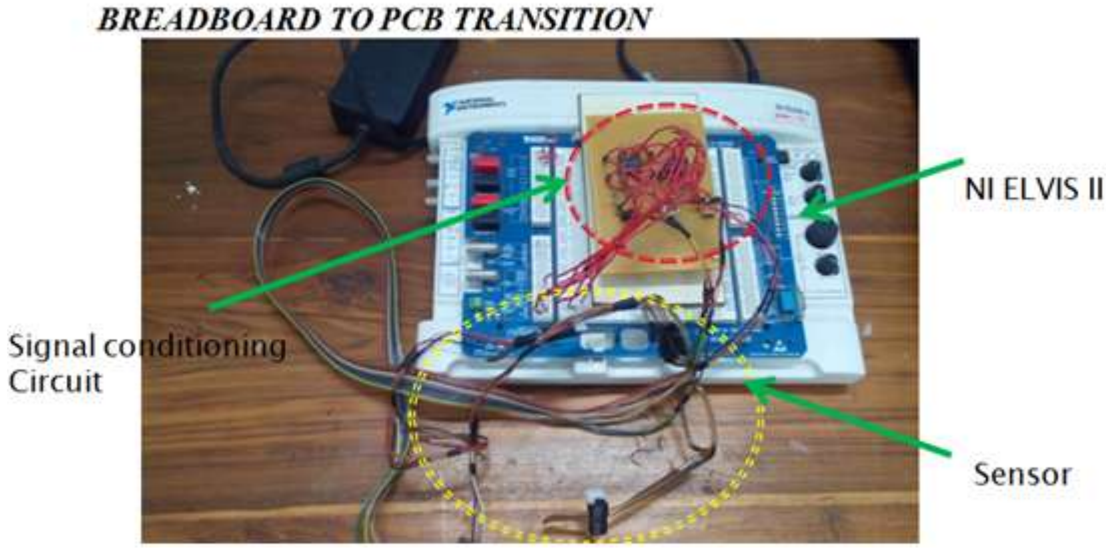


Figure 3.21: Prototype setup on PCB

3.6. DATA ACQUESTION SYSTEM (DAQ)

The purpose of data acquisition is to measure an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound. PC-based data acquisition uses a combination of modular hardware, application software, and a computer to take measurements. While each data acquisition system is defined by its application requirements, every system shares a common goal of acquiring, analyzing, and presenting information. Data acquisition systems incorporate signals, sensors, actuators, signal conditioning, data acquisition devices, and application software [6].

Data Acquisition is the process of:

- Acquiring signals from real-world phenomena
- Digitizing the signals
- Analyzing, presenting and saving the data

In this project the National Instrument Educational Laboratory Virtual Instrument Suite (NI ELVIS) uses LABVIEW based software instruments and a custom- designed benchmark workstation and prototyping board to provide the functionality of a suite of common laboratory instrument. The NI ELVIS hardware provides fixed and variable power supplies from the bench top workstation.

During initial phase of design and development of hardware, NI ELVIS was used as the workstation and DAQ from LABVIEW are used as signal conditioning using band pass filter block and also used as a display of output signals using Figure. Before we use signal conditioning circuit signal output from the sensor is filtered digitally by filter express VI from LABVIEW.

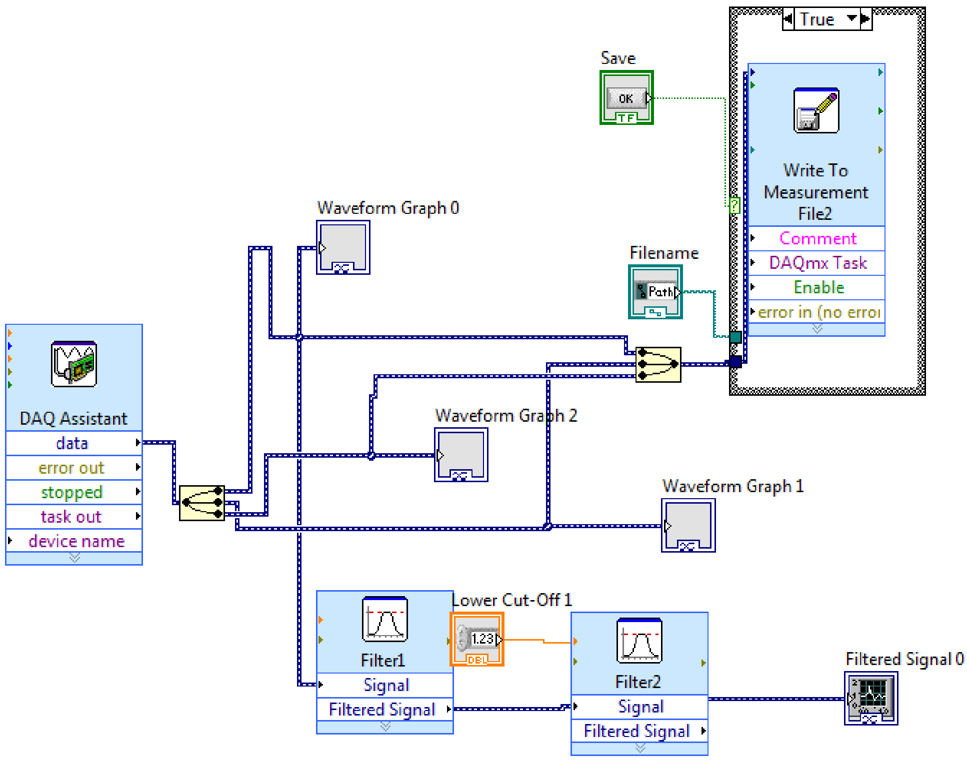


Figure 3.22: Signal conditioning using LAB VIEW

PPG signal from signal conditioning circuit as shown in Figure 3.20 using LabVIEW waveform Graph 0 display s shown in figure 3.22.

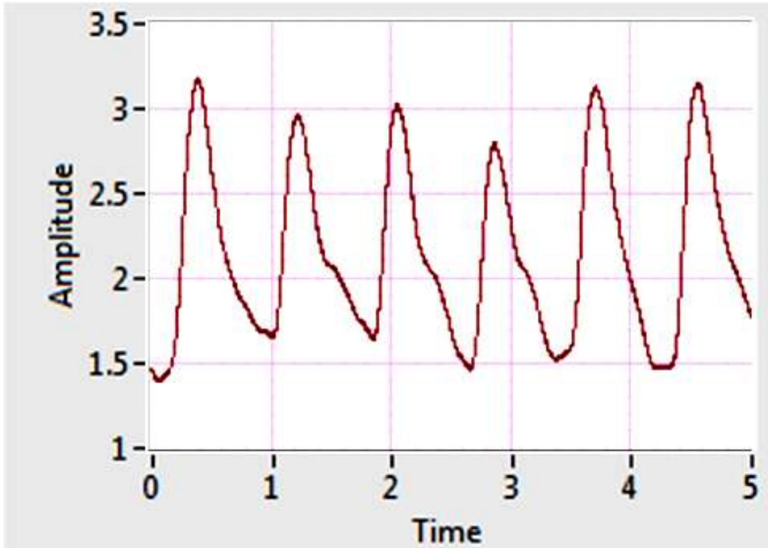


Figure 3.23 PPG signal from second stage signal conditioning circuit

The two stages of filtering and amplification signal given to Arduino ADC to converts the input PPG signals to near TTL pulses as shown on Figure 3.24 using AnalogRead() of Pro Mini Arduino.

The Arduino board contains has 8 channels, 10-bit analog to digital converter. This means that it will map input voltages between 0 and 5 volts into integer values between 0 and 1023. This yields a resolution between readings of: 5 volts / 1024 units or, 0.0049 volts (4.9 mV) per unit. TTL output signal as shown on Figure 3.22 measured from digital pin 2 of Arduino pro-mini.

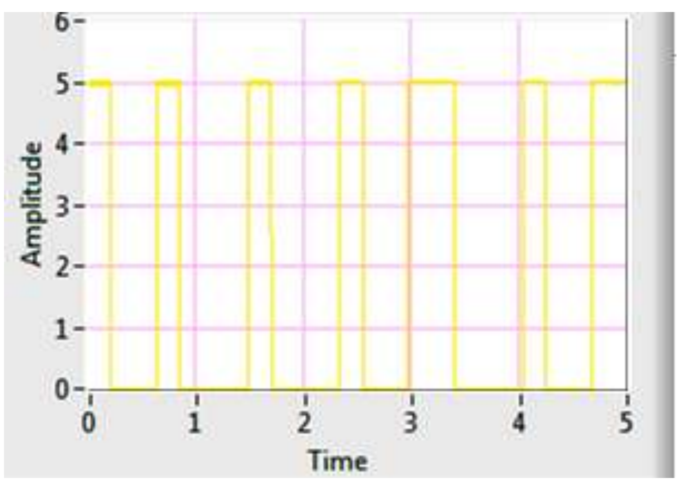


Figure 3.24: TTL pulse from Arduino digital pin 2

3.7. TRIAL WITH CAR

To decide the position of the sensor a short trial on the car was conducted with prototype setup. The main objective behind the test is to check the stability of the PPG signal and variation of heart rate during driving on the three surface of the body such as Temple, Nose and Near to Ear as shown figure 3.25 below. During this test we have recorded using LabVIEW block called write to measurement file as shown in figure 3.22.

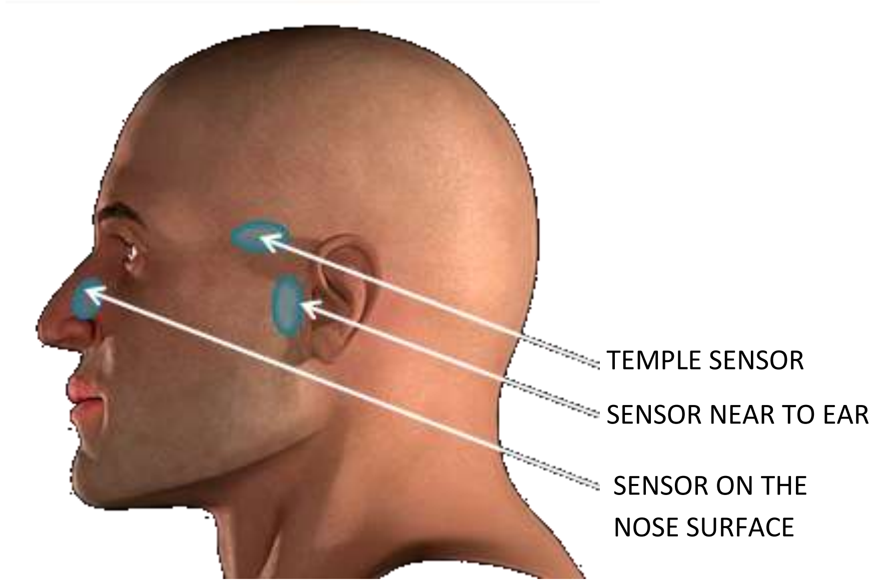


Figure 3.25: Sensor position during car test

The three sensors were integrated on the **spectacle** frame of the driver and set-up was held with bread board, Elvis board and laptop by the back seat of the car as shown on Figure 3.26. The test was conducted from North East entrance of Electrical department, Indian Institute of Technology Madras to the main Gate of IIT Madras for the duration of around 15 minutes. During the trial we record the data using LabVIEW from three surface of the body at the same time using LabVIEW Write to measurement file block as shown in figure. During the record, the car was driven at the various speeds on the road bumps to ascertain the reliable detection of Heart Rate from PPG signal.

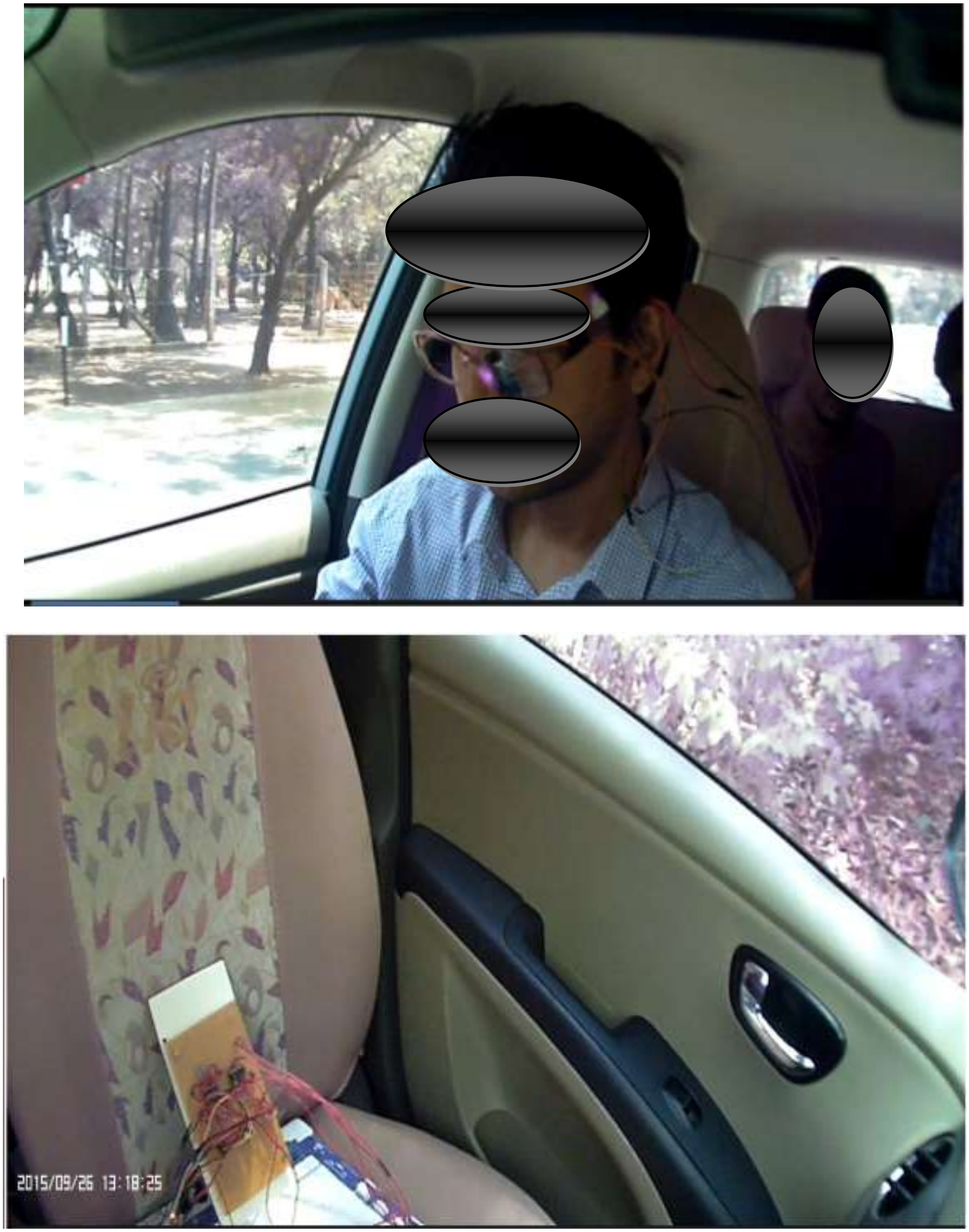


Figure 3.26: Experimental test setup in the car

The sensor is placed in the temple, on Nose surface and near to Ear surface of the driver.

3.8. TRIAL PPG SIGNAL WAVEFORM WITH CAR

3.8.1. PPG signal from Temple Sensor

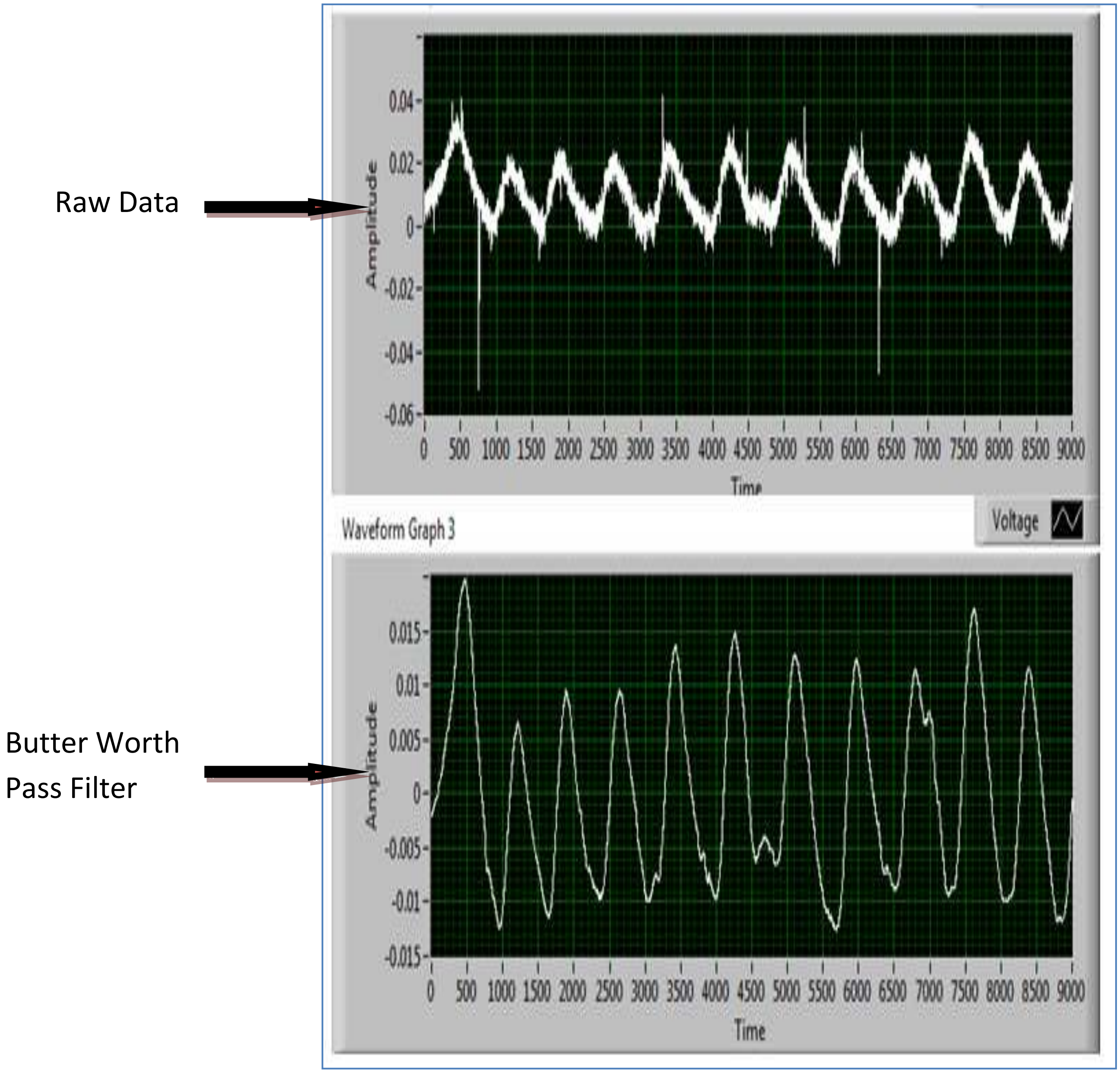


Figure 3.27: PPG signal from Temple Sensor

As we can see from the Figure 3.27 the PPG signal from the Temple sensor was quite stable during trial and less affected by the bumps of the road.

3.8.2. PPG signal from near Ear Sensor

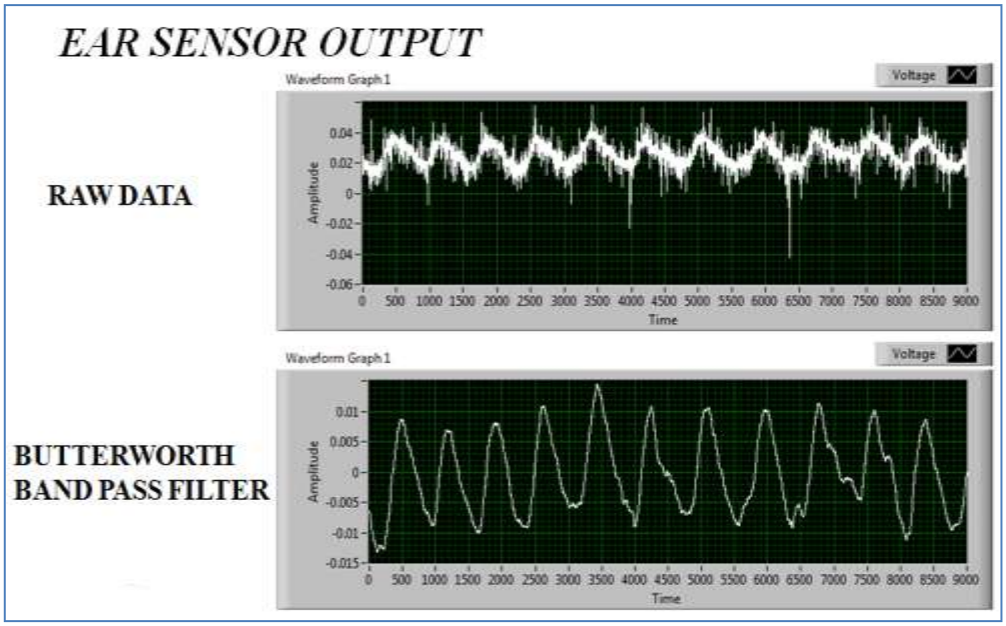


Figure 3.28: PPG signal from near Ear sensor

The PPG signal from the Ear sensor was stable and less affected by the bumps of the road as show in Figure 3.28.

3.8.3. PPG signal from the surface of Nose

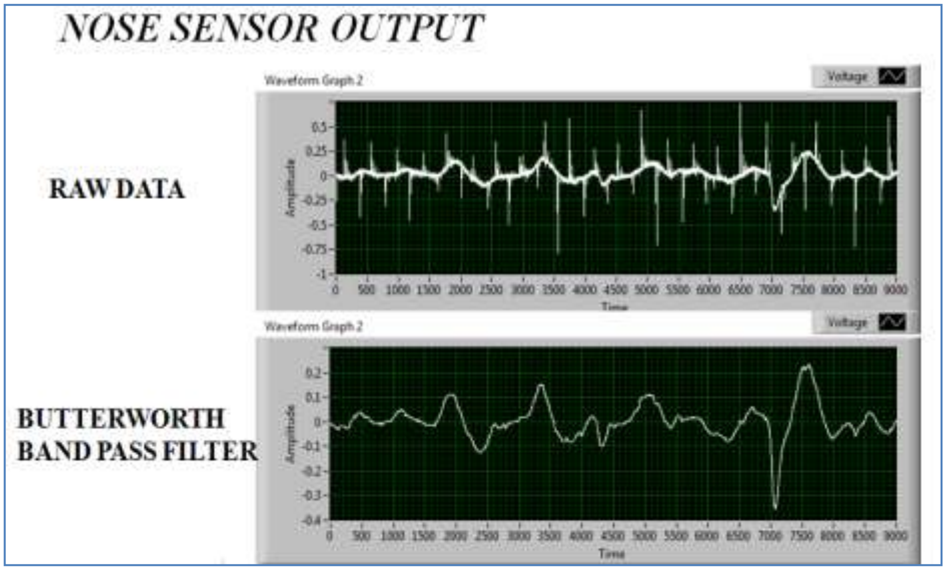


Figure 3.29: PPG signal from Nose surface sensor

The PPG signal from the surface of the Nose is not that much stable and its highly affected by the bumps of the road as shown in the Figure 3.29.

CHAPPTER 4

ANDROID APPLICATION DEVELOPMENT

Using App Inventor 2 which is a web-based online graphical mobile application development environment for Android devices, we create an application by simply drag and connect a series of function blocks. To use App Inventor first we have to create a Google account. After login to the system using a Google ID, from the App Inventor Designer menu, you can click on Start new project to start a new program, as shown below:

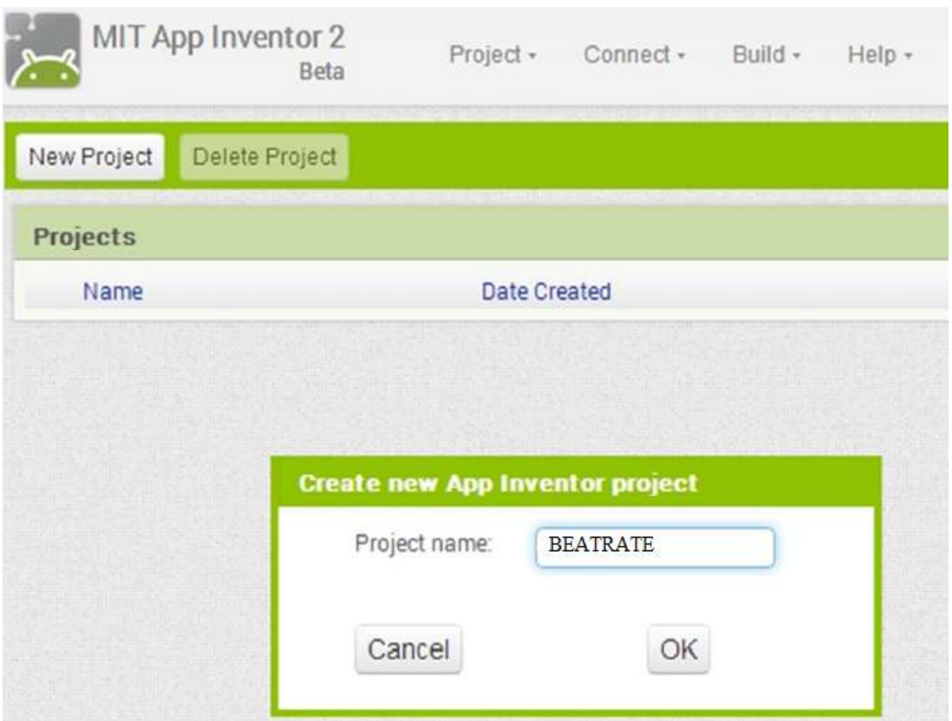


Figure 4.1: App Inventor Designer menu (application starting screen)

Enter "**BEATRATE**" as a project name and click OK to continue. At this point, the App Inventor designer is showing 4 separate sections **Palette**, **Viewer**, **Components** and **Properties** as shown on Figure 4.2.

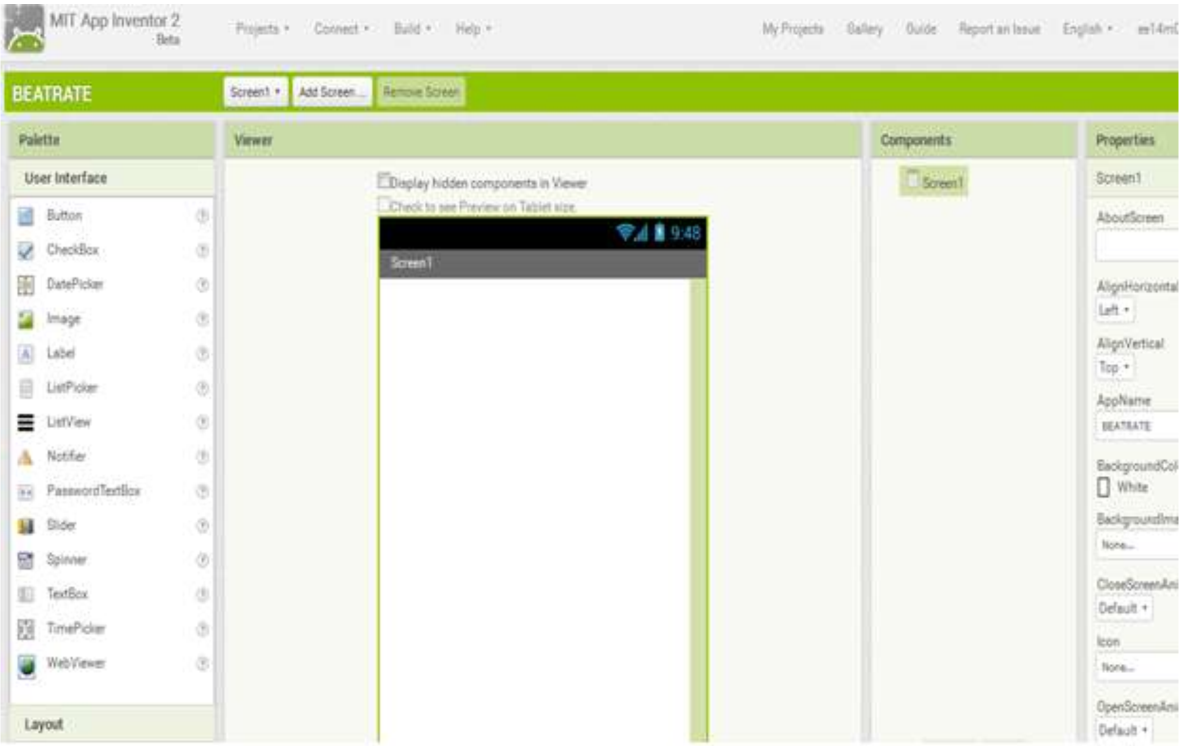


Figure 4.2: App Inventor Designer section

- **Palette**: This section contains different components which you can drag onto the Viewer to add them to your application. This is a familiar feature to the .NET developer.
- **Viewer**: This section provides a preview screen for your application where you can drag and drop components from the Palette section onto the screen and arrange the components to see how your app will look like.
- **Components**: This section lists all of the components that are added to your application. By clicking on a component, the selected component's properties are shown on the Properties section.
- **Properties**: This section displays all of the properties associated with a selected component and provides the interface for you to edit and change the setting or value for each of these properties.

From the Palette section, select and drag the *Lebel1* component to the Viewer section "Beat Rate…" as *Lebel1* name that used as the beat rate data display. From the same section, select and drag the *ListPicker1* and *Button1* to the viewer section "connect Bluetooth" and "disconnect

Bluetooth" as the name of *ListPicker1* and *button1* respectively. In the Design screen, below, you can see the depiction of an Android device screen:

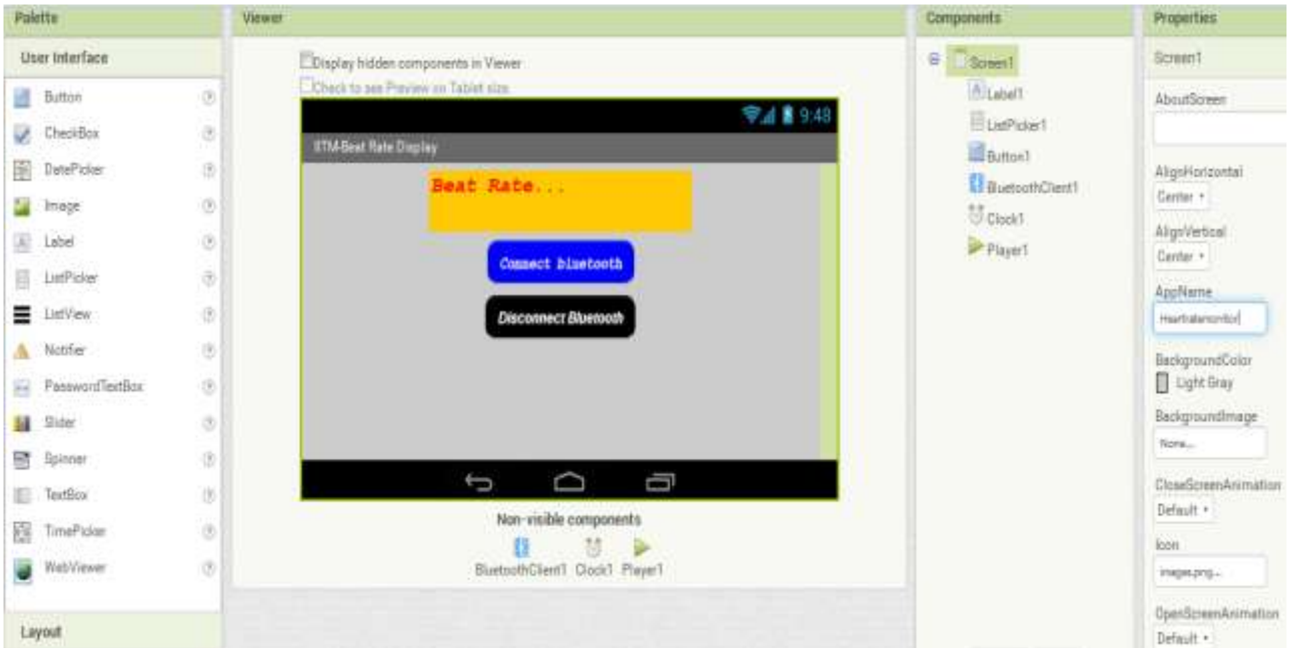


Figure 4.3: BEAT RATE design screen

On the left of the screen is a list of the components which can be dragged and dropped onto the Android screen.

To the immediate right of the Android screen is a list of the current screen components: a *Lebel1*, *ListPicker1*, *Button1* and *horizontal arrangement*. There is also a non-visible components like Bluetooth client, clock and player1 at the bottom of the screen.

To the far right of the Android screen are the properties of the currently selected component - in this case the ***Screen1*** is selected as shown on Figure 4.3.

If we click on the Blocks Tab for instance, click on the ***ListPicker1*** component on the left hand side of the screen. A scrollable list of code blocks relevant to the ***ListPicker1*** appears. Click on

“When *ListPicker1* BeforePicking” and it will be placed onto the Blocks screen area as shown on Figure 4.4.

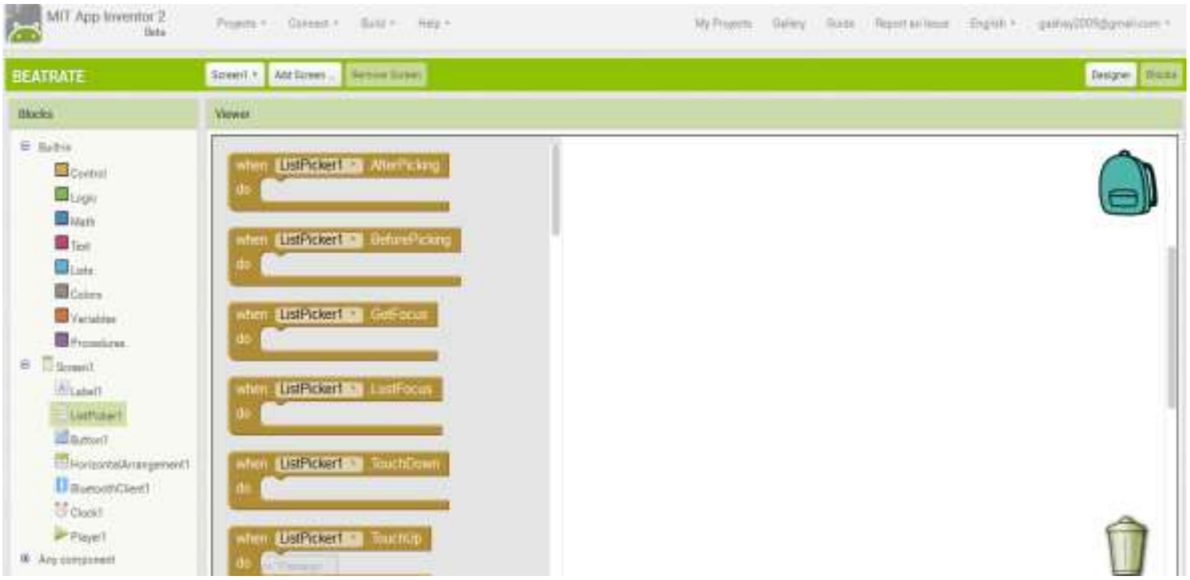


Figure 4.4: App Inventor Designer Block screen

4.1. ANDROID–BLUETOOTH COMMUNICATION APPLICATION FLOW CHART

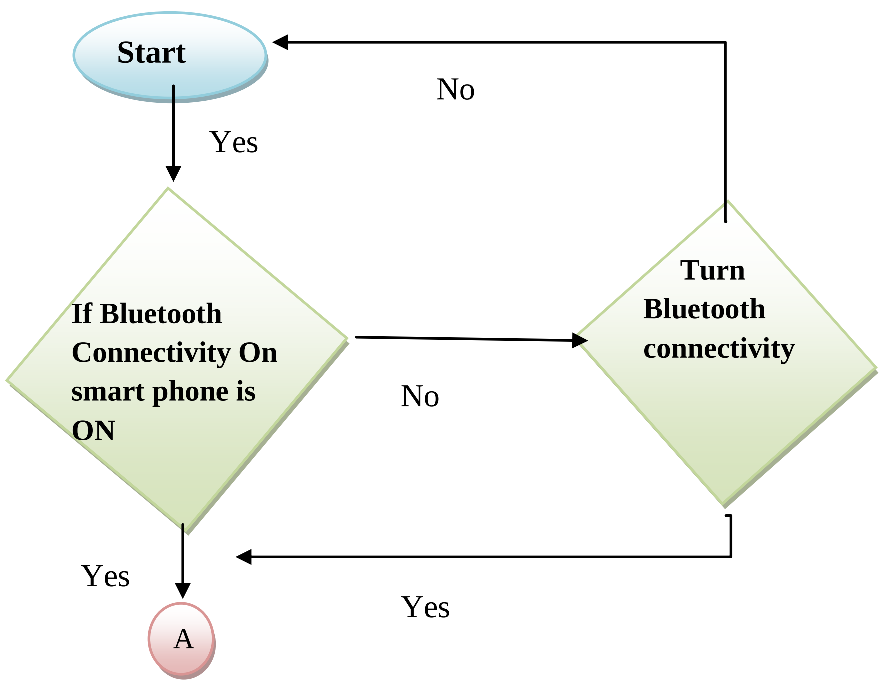


Figure 4.5: A Flowchart for Bluetooth Module and Android Smartphone connection flowchart

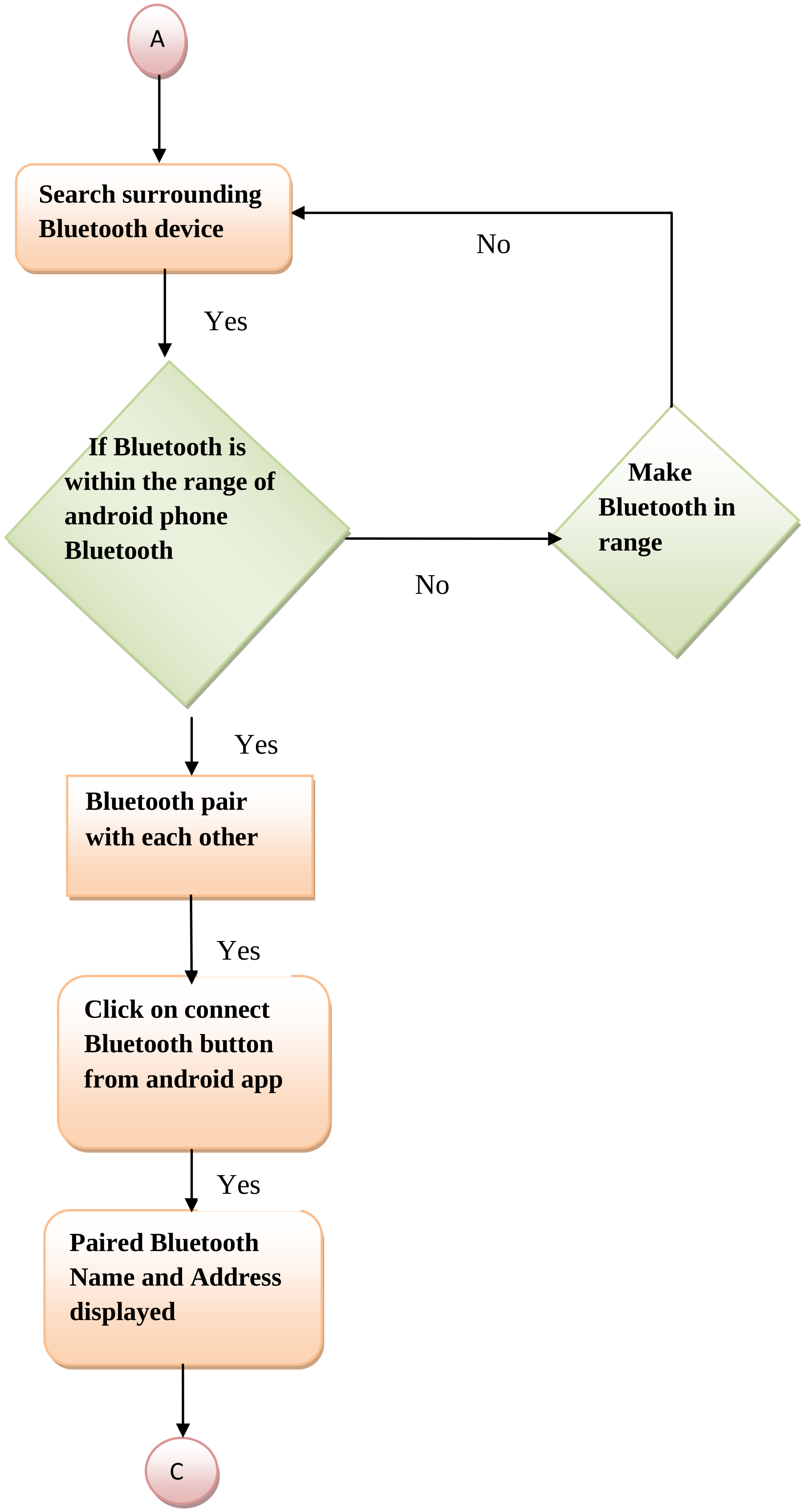


Figure 4.5: B Flowchart for Bluetooth Module and Android Smartphone connection flowchart

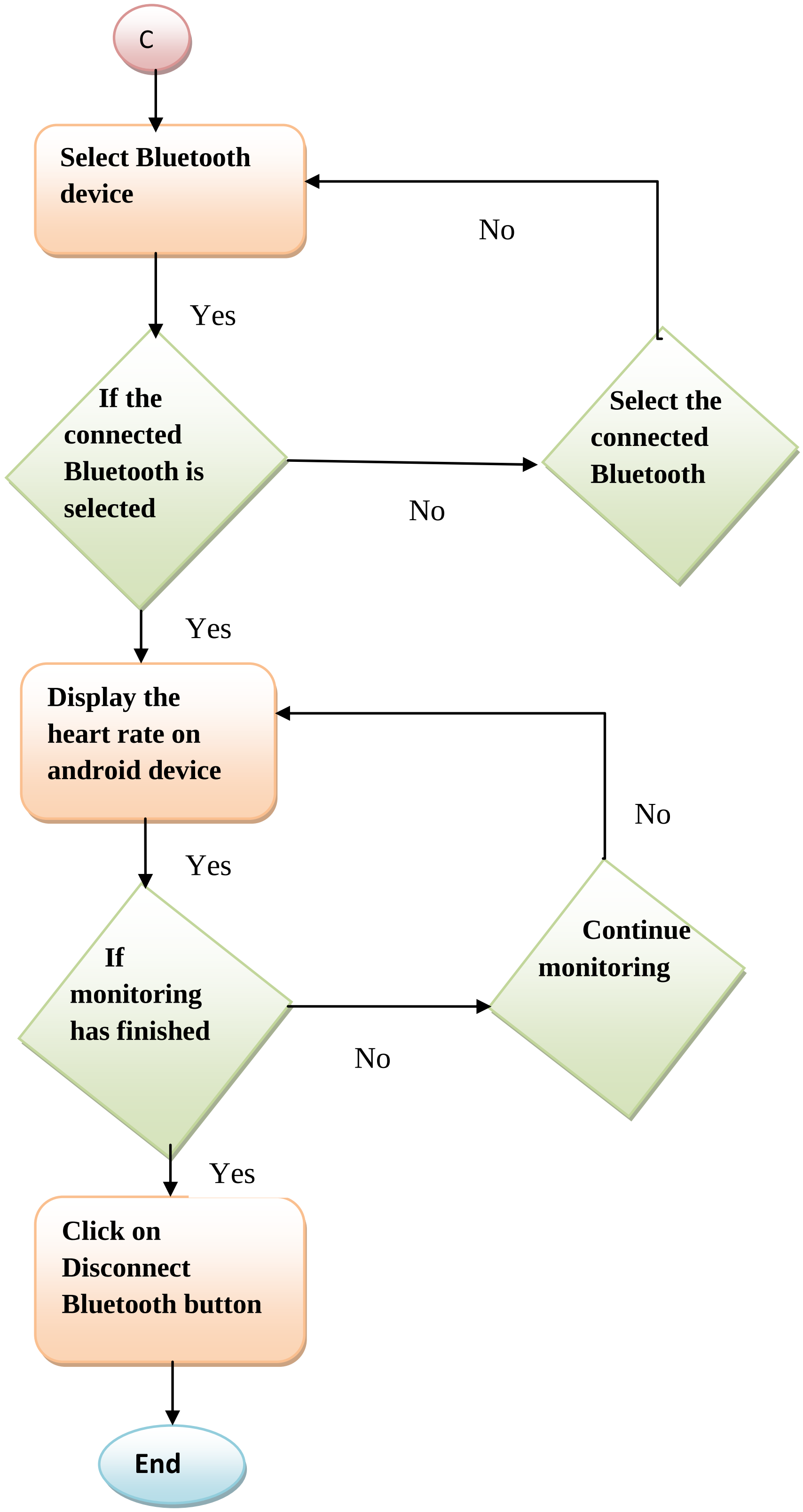


Figure 4.5: C Flowchart for Bluetooth Module and Android Smartphone connection flowchart

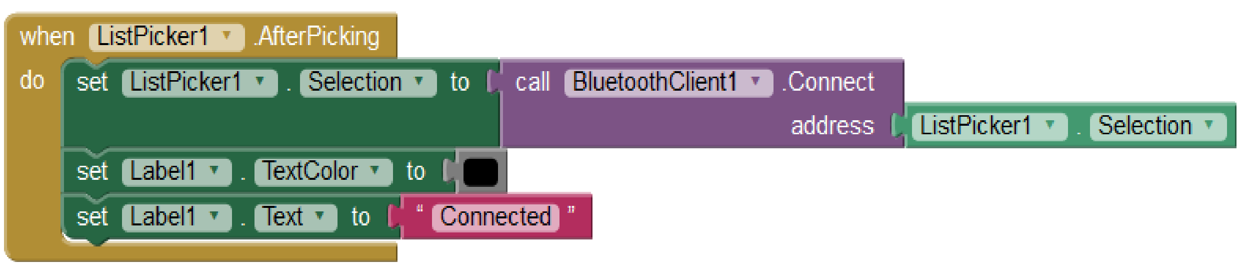
We can now select further sub-Blocks to create the first full code Block, below.

4.2. CODE BLOCK

4.2.1. Connecting Bluetooth

When the two devices are running, the server app is set up first to accept connections. Then, on the client side, the user selects the Connect *ListPicker1* button and selects the device name from a list of available Bluetooth devices. Because the list of devices is in the form of a list, the *ListPicker1* is a great interface component to display the device list and handle the selection. In general this allows ***ListPicker1*** to display the available (already paired) Bluetooth devices.

The next Block allows ***ListPicker1*** to select and connect to the desired Bluetooth device and to set the "hidden" Label, ***Label1*** to read "CONNECTED":



We have then set the default Text of ***Label1*** to be "Disconnected" and the colour of ***Label1*** to be Red in the Design Screen; clearly, ***Label1*** is now no longer "hidden".

We have also added a further component into the code Block, to set the Text colour of ***Label1*** to be Black when the Bluetooth client is connected.

When we click the "Bluetooth connect" button the figure shown blow is displayed.

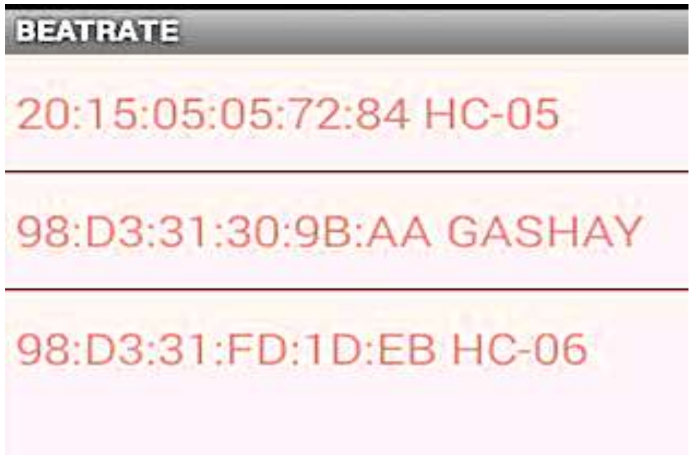


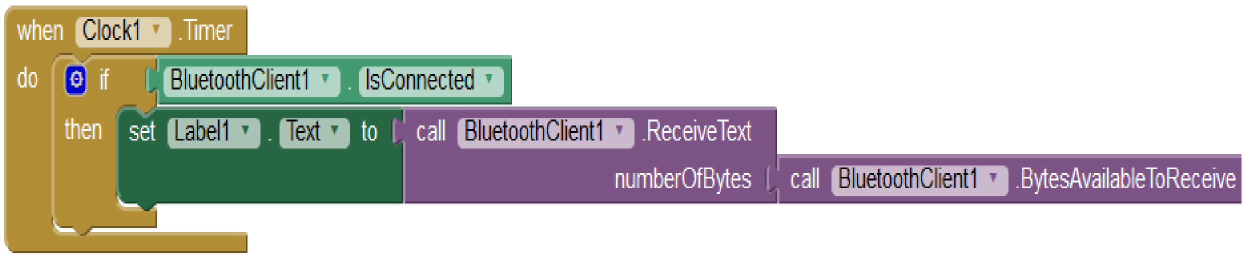
Figure 4.6: Paired Bluetooth option

After selecting “paired” Bluetooth we can check whether the device is connected or not by clicking on “connected Bluetooth” the hidden label, ***label1*** to read “connected” which is displayed as shown Figure below.

Figure 4.7: Checking Bluetooth device is whether connected or not

4.2.2. **Receiving Data**

The reception of data is implemented using a timer. Once per second, the client checks to see if data is available, and if it is, reads and displays the data on the app display.



After the device has been selected, as shown on figure 4.5 above, with the *ListPicker* (Bluetooth connect) user interface, the *Connect* method of *BluetoothClient1* establishes the connection. The method returns a value of *true* if the connection was successful; in which case a message is sent to the server app. The data is sent to android device is displayed as shown on Figure 4.7 when the Bluetooth and the device is successfully connected.

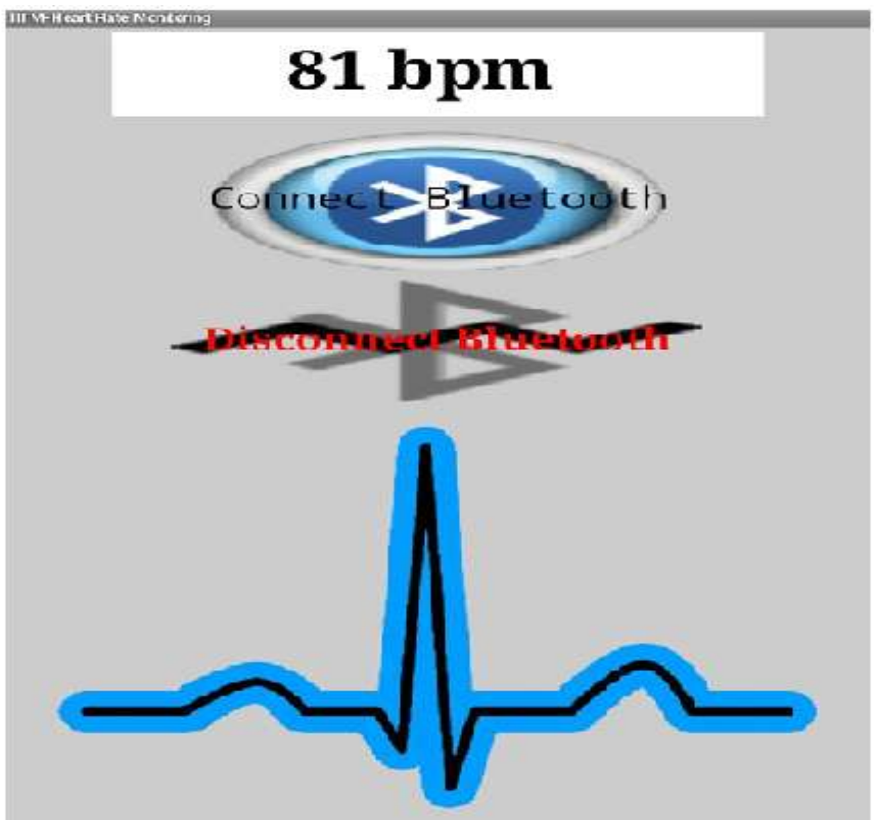
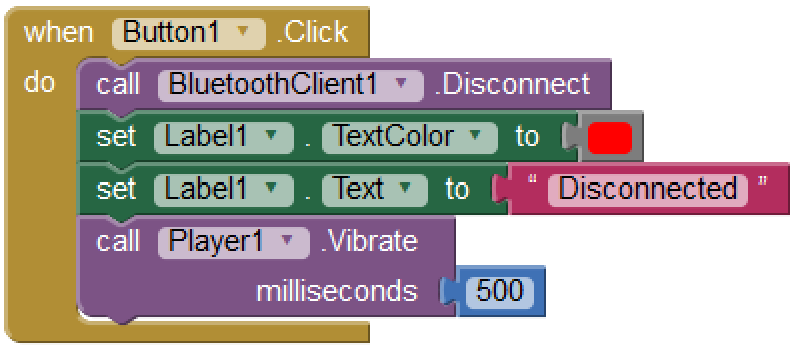


Figure 4.8: Beat per minute displayed on android device

4.2.3. Disconnecting Bluetooth

Finally, we have added the Button1 in the Design screen with a Text value of "Disconnect Bluetooth" and a fourth Block of code which disconnects the Bluetooth client, sets **Label1** text colour to Red and **Label1** text to read "Disconnected"

We have also added a further component "Player1" into the code Block, to set the 500ms vibration of Android device when the Bluetooth client is Disconnected.



To disconnect the android device and Bluetooth client simply click on the "Disconnect Bluetooth" button, the Clock component stop receiving data and Lebel1 will show the "Disconnected" message as shown Figure 4.8.

Figure 4.9: Disconnect Bluetooth device

Before you use the Bluetooth communications apps, do the following:

1. Use Build .apk or other method to obtain the server app, download and install on your first Android device as figure 4.9 shown below.
2. Go in to the Android Settings and turn on the Bluetooth feature. The user interface for the Bluetooth configuration varies slightly depending on which version of Android you have. For example, on Android 5.0, Bluetooth appears in the topmost Settings menu.
3. In newer versions of Android, when the Bluetooth Settings menu is active, your device is broadcasting its availability to other nearby devices. On older versions, you may need to click an option to make your device "discoverable".
4. Once your two devices see each other over Bluetooth, you may be prompted to **"pair"** the devices, or (depending on Android version), you may have to manually choose the device and then choose pairing. Follow the on screen instructions.
5. Once the two devices are "paired", launch the Server app and select Bluetooth device.
6. If we want to check whether the device is connected or not click on "Bluetooth connect" and Connected message is displayed on the screen.
7. Final we can install .apk file to any android device show in Figure 4.9 as name "BEATRATE".

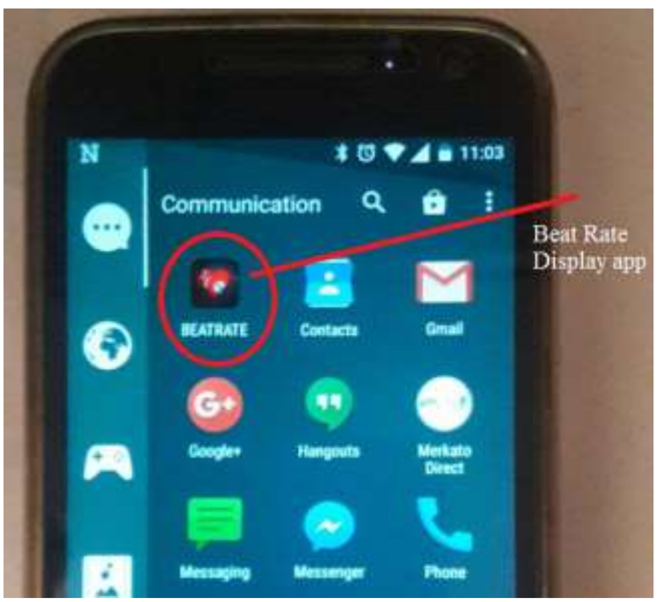


Figure 4.10: Android app inventor application installed on android device

CHAPTER 5

EXPERMENTAL SETUP

5.1. SENSOR AND OTHER COMPONENTS INTEGRATED WITH HEADPHONE

The TCRT1000 Sensor, Arduino pro-mini, HC-05 Bluetooth module, DC-DC Boost Converter Step Up Module 1-5V to 5V 500mA, double layer signal conditioning PCB and 2 AAA battery are integrated with the headphone. The position of the components is placed as shown in figure 5.1 below.

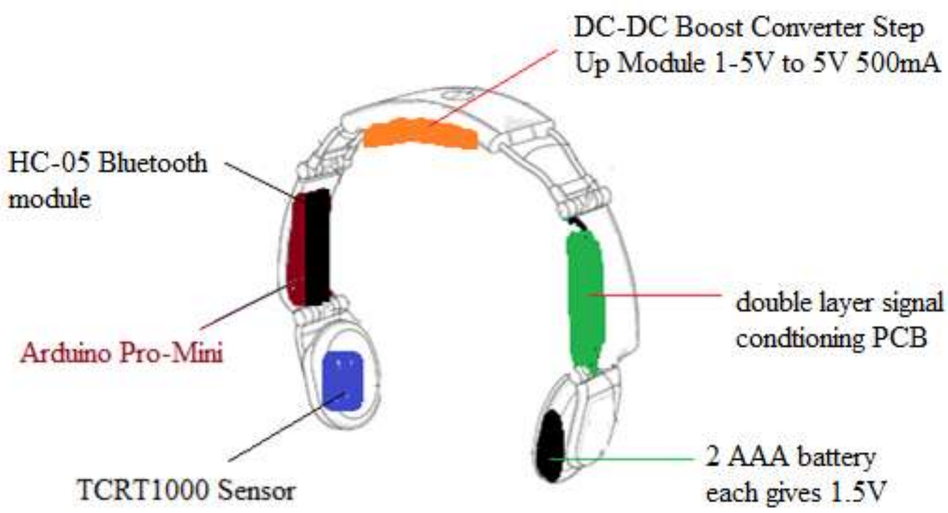


Figure 5.1: Component integrated into headphone

The TCRT1000 sensor can also be connected to the board through header pins and jumpers. The sensor is integrated with the headphone on the ear bad. This technique is used especially for driver drowsy detection and physical activities to reduce the motion artifact and to make it more flexible.

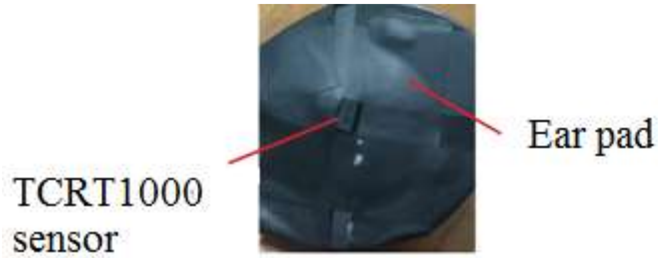


Figure 5.2: sensor integrate with headphone on ear pad

5.2. POWERING OF THE BOARD

In this project we have used Intex Wireless Roaming headphone which has 2 AAA batteries each gives 1.5V and for sensor integration on the ear pad and holding the signal conditioning board, Bluetooth and Arduino board on the headband. The total output voltage from this headphone is maximum 3V but for our system we need 5V supply.

Figure 5.3: Intex Wireless Roaming headphone

To get the required voltage from headphone to power the board we use the device called DC-DC Boost Converter Step Up Module 1-5V to 5V 500mA. This device Input any DC voltage of 1V - 5V, output 5V DC voltage is stable, the input to the output current of 500 - 600mA with two AAA batteries, a single AAA battery power supply output current 200ma about for mobile phones camera, single-chip, digital products supply.

Figure 5.4: DC-DC Boost Converter Step Up Module 1-5V to 5V 500mA [11]

DC-DC Boost Converter Step Up Module 1-5V to 5V 500mA description

1. High conversion efficiency, up to 96%
2. Input voltage: 1V~5V
3. Output voltage: 5V
4. Output Current: 500mA
5. PCB size: 17.55mm x25.22mm x5.85 mm
6. Size: 17.55 x32.53 x8.3mm

The operation of the board is very simple. After powering the board with 5V supply IR sensor becomes active. Next, place the IR sensor near to the Ear using headphone. You can feed the output signal (V_{out}) from the second low pass filter stage that is PG signal to analog input pin of Arduino board for measurement of the heart beat rate in BPM. The output voltage waveform can also be viewed on an oscilloscope or LABVIEW. We use LABVIEW oscilloscope to view the input PPG and the output waveforms from the second low pass filter stages. The following pictures show these signal waveforms as displayed on the PC screen.

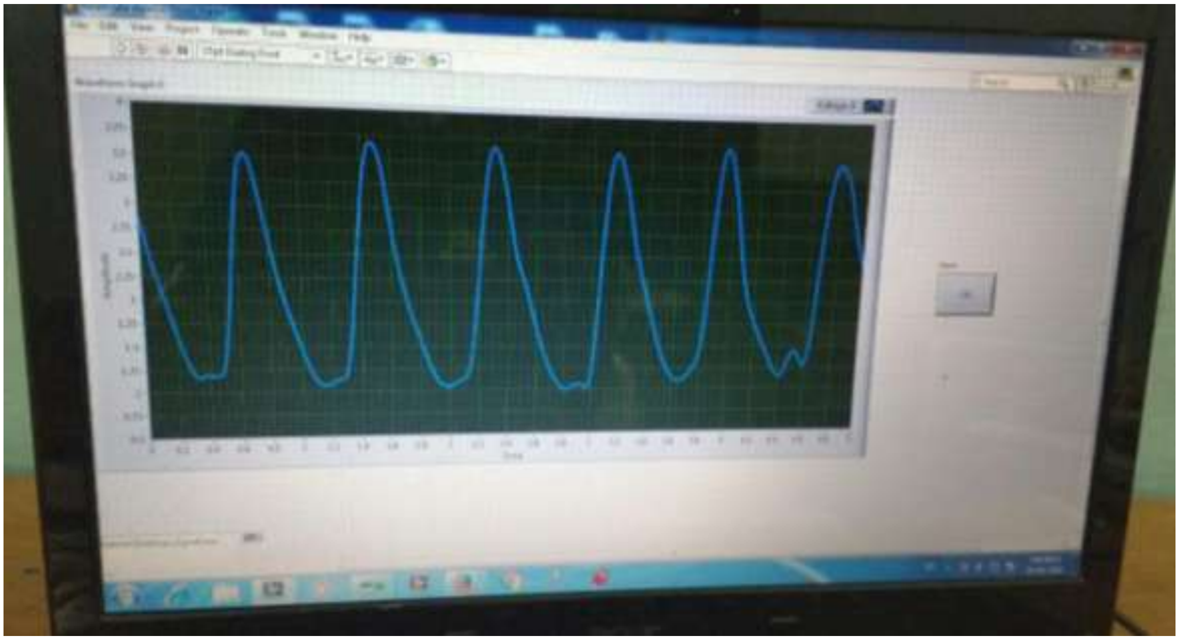


Figure 5.5: PPG signal

The PPG output signal can be connected to analog input pin of Arduino board and digitalize this signal using Arduino ADC to find its frequency. If you multiply the frequency by 60, you will get the heart rate in BPM. The BPM is display using Android device through Bluetooth communication. We create an application by simply drag and connect a series of function blocks for Android device using App inventor 2 which is web-based online graphical mobile application development environment.

5.3. PCB DESIGN AND FABRICATION

A dual layer PCB has been designed and components mounted on that as shown in Figure 5.6 PCB layouts, both component side and the solder side, are attached as Appendix-C

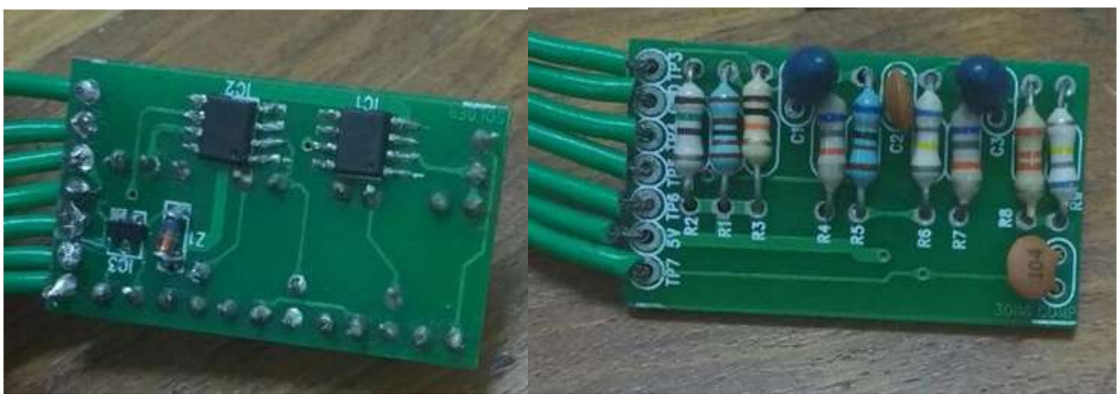


Figure 5.6: Dual layers PCB of signal conditioning part

On the component side capacitor and resisters are placed and on the solder side SMD Op Amp, SMD transistor and SMD Zener diode are soldered as shown on the figure 5.6 from left to right. This PCB consist seven holes 5V, GND, PPG output (TP7) and TP3-TP6 connector for the infrared TCRT1000 sensor. The 5V and GND connected to DC-DC Boost Converter Step Up Module 1-5V to 5V 500mA, TP7 connected to Arduino pro-mini analog pin (A0) and TP3-TP6 connected to TCRT1000 sensor using jumper or directly wired.

Arduino pro min and HC-05 are connected back to back as shown in figure 5.6. Internally the transmitter (TX) and receiver (RX) of Arduino pro-mini connected with the receiver (RX) and transmitter (TX) of Bluetooth respectively and the Vcc with Vcc and GND with GND of Arduino pro-mini and Bluetooth also connected. The three wire analog pin(A0), Vcc and GND are taken to give analog signal (PPG signal) and power the device.

Figure 5.7: Arduino pro mini and HC-05 Bluetooth connection

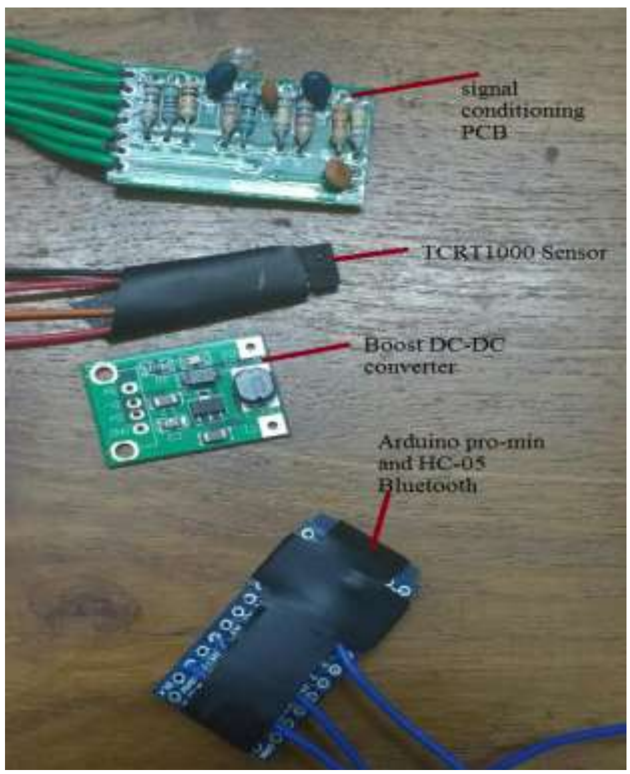


Figure 5.8: Signal conditioning PCB, DC-DC Boost Converter Step Up Module, TCR1000 Sensor and HC-05 Bluetooth module and Arduino pro-min.

The overall system shown below, signal conditioning circuit, pro mini Arduino and HC-05 Bluetooth integrated on the headphone headband and the sensor also integrate on the headphone ear pad. The PPG signal waveform displayed on the laptop using LabVIEW software and the heart rate per minute displayed on the Android device using Bluetooth communication and MIT app Inventor application shown below.

Figure 5.9: Heart Rate Monitoring System Integrate With Headphone

Figure 5.10: Heart Rate Monitoring System using Bluetooth Communication and Android display

5.4. MEASURING OF HEART RATE

For human, the normal resting heart rate can be anywhere between 60 and 100 beats per minute. Usually the healthier or filter you are, the lower your rate. Anew born may goes to 140 bpm and a competitive athlete may have a resting heart rate as low as 40-55 beats per minute.

Test was performed on few volunteers in our lab and hostel friends to check and verify accuracy of heart rate measurement with ±3 beats as a tolerance during normal resting period.

Table 5.1 Heart Rate measurement of different peoples

Subject	Age	Male/Female	Actual heart rate (bpm)	Measured heart rate (bpm)	Difference (bpm)
A	33	M	60	62	-2
B	33	M	60	63	-3
C	24	M	92	93	-1
D	25	M	76	78	-2
E	28	M	78	76	+2
F	25	M	78	80	-2
G	24	M	82	80	+2
H	28	M	90	88	+2

The Table 5.1 shows the heart rate measurements taken from few friends from IIT Madras for checking against the physical heart rate.

5.5. MEASURMENTS OF HEART RATE VARIABILITY (HRV)

In the second phase, the heart rate variability was obtained from my own heart rate at different time period of a day with fixed time interval. To know the heart rate variation the data was recorded with an hour interval of a day. The data showed a considerable change in heart rate activeness to sleep.

Table 5.2 heart rate variation of a subject at fixed time interval

Time	7:00 AM	9:00 AM	11:00 AM	1:00 AM	3:00 PM	5:00 PM	7:00 PM	9:00 PM	11:00 AM	1:00 AM	3:00 AM	1:00 AM
Measured HR (bpm)	84	87	84	84	90	80	81	84	83	80	75	88

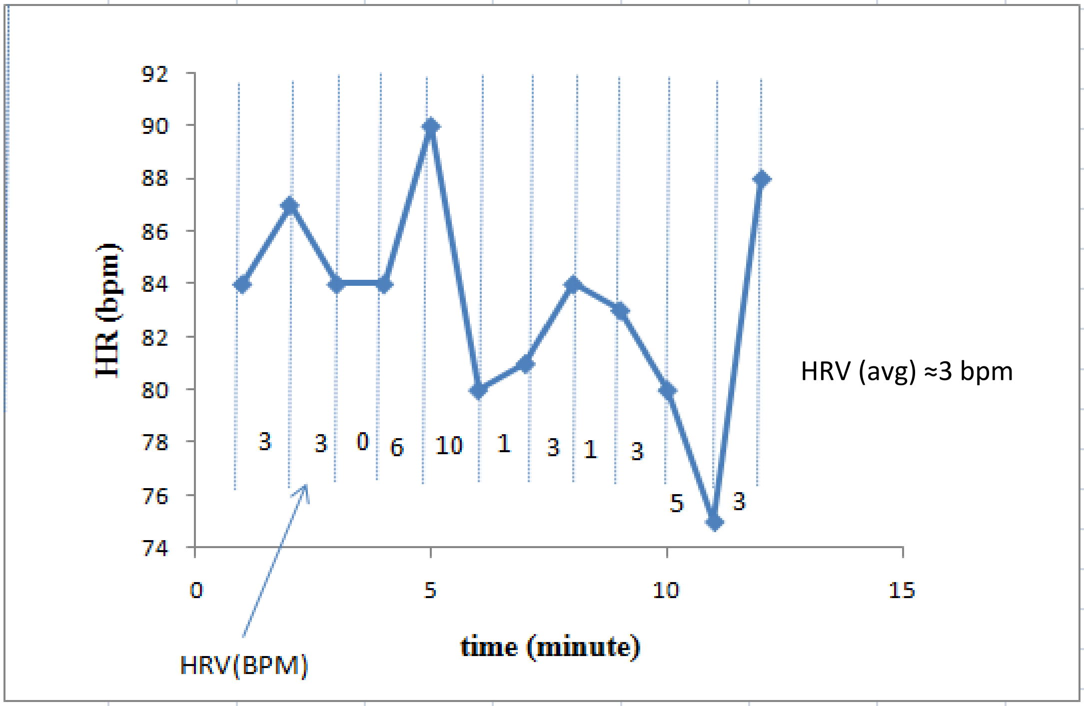


Figure 5.11: Heart Rate Variation of the subject within a day

The entire sample we have taken is 12 data within one day with two hour interval. It can be inferred from table 5.2 or from figure 5.11, that the heart rate varies from 75 bpm to 90 bpm within one day for this subject. In general, the heart rate variability and the average heart variability can be calculated using the formula:

HRV = peak high rate - peak low rate

and

HRV(av)= [((peak high rate 1 - peak low rate 1)+…..(peak high rate n -peak low rate n))/n]

$= HVR_1 + HVR_2 + \ldots\ldots\ldots\ldots + HVR_n$

When n is the number of sample

CHAPTER 6

CONCLUSION, SUMMARY AND FUTURE OF THE PROJECT

6.1. CONCLUSION

This thesis presents the implementation of heart rate monitoring system using Reflectance PPG sensor involving low cost pro mini arduino board, HC-05 Bluetooth and other easily available resources. This project was successfully implemented and the output PPG signal displayed on the PC using LabVIEW. Data transmission from arduino to the smartphone via HC-05 Bluetooth communication was achieved. Heart beat for one minute is counted and the output is displayed on the android device using MIT App Inventor 2 application used as display which is a web-based online graphical mobile application development environment.

The design for this product is geared to produce a device that can act as a drowsy detection for driver, anger detection and personal trainer. The driver can check his/her drowsiness at any time using his/her android phone. This system can be employed in hospitals also. Here according to the proposed system doctor does not need to be present while monitoring the heart rate. The doctor can receive the heart rate of patient remotely.

We should carefully consider the device has the advantages and drawbacks of the optical ear pad sensor method when designing an application. There are some clear advantages. First of all, it is noninvasive and the PPG signal is strong, robust, portable and low power consumption and it can be used by non-professional people at home to measure the heart rate easily and safely. The drawbacks, however, are the motion artefacts and not precise. The alternative for heart-rate measurements is to use ECG and detect the heart-rate from the R-R intervals.

6.2. SUMMARY

Heart rate monitoring system using Reflectance PPG technique provides a reflective IR sensor with necessary instrumentation circuit to illustrate the principle of photoplethysmography as a noninvasive technique for measuring heart rate. In order for this sensor to work, the sensor, which is integrated to headphone ear pad, should be placed gently over the surface of the body near to Ear and be kept still. The sensor may also be wired to the board through a 4-pin jumper and header pins or can wire directly with signal conditioning PCB. Connecting the sensor using 4-pin jumper gives more flexibility of using the sensor as you can place the sensor over the skin on palm, or wrap around a fingertip using paper or duct tape other than near to Ear surface. Integrating the sensor with headphone on the ear pad surface performance would not be affected too much by a slight movement of the person.

6.3. **FUTURE WORK**

The current version of the Processing application displays the near-real-time PPG waveform and heart rate but does not record anything. There is a lot of room for improvements. The device can be improved in certain areas as listed below:

- Recording the PPG signal as well as heart rate per minute can be added for future reference
- Sound can be added to the device so that a sound is output each time a pulse is received.
- Warning or abnormalities (such as very high or very low heart rates) can be displayed on the android device or indicated by an LED or a buzzer.
- Signal conditioning circuit, Atmega328p, HC – 05 Bluetooth and DC-DC step-up boost converter can be build on the same PCB.
- Can be avoiding sensor attachment on the surface of body to reduce motion artifact.

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APPENDIX A

Arduino and Bluetooth HC-05 connection

To make a link between your Arduino and Bluetooth, do the following**:**

1. Go to the Bluetooth icon , right click and select Add a Device

2. Search for new device , Our Bluetooth module will appear as HC-05 , and add it

3. The pairing code will be **1234.**

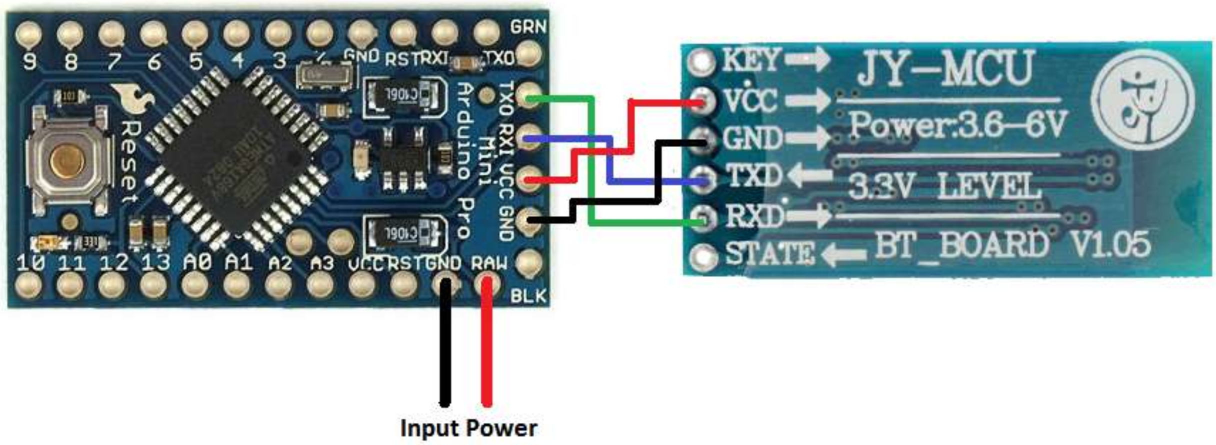

Figure A.1: Arduino and Bluetooth HC-05 connection

APPENDIX B

Arduino and LCD Connection

Creates a variable of type LiquidCrystal(). The display can be controlled using 4 or 8 data lines. If the former, omit the pin numbers for d0 to d3 and leave those lines unconnected. The RW pin can be tied to ground instead of connected to a pin on the Arduino; if so, omit it from this function's parameters.

Syntax

LiquidCrystal(rs, enable, d4, d5, d6, d7)

LiquidCrystal lcd(13, 12, 6, 5, 4, 3);

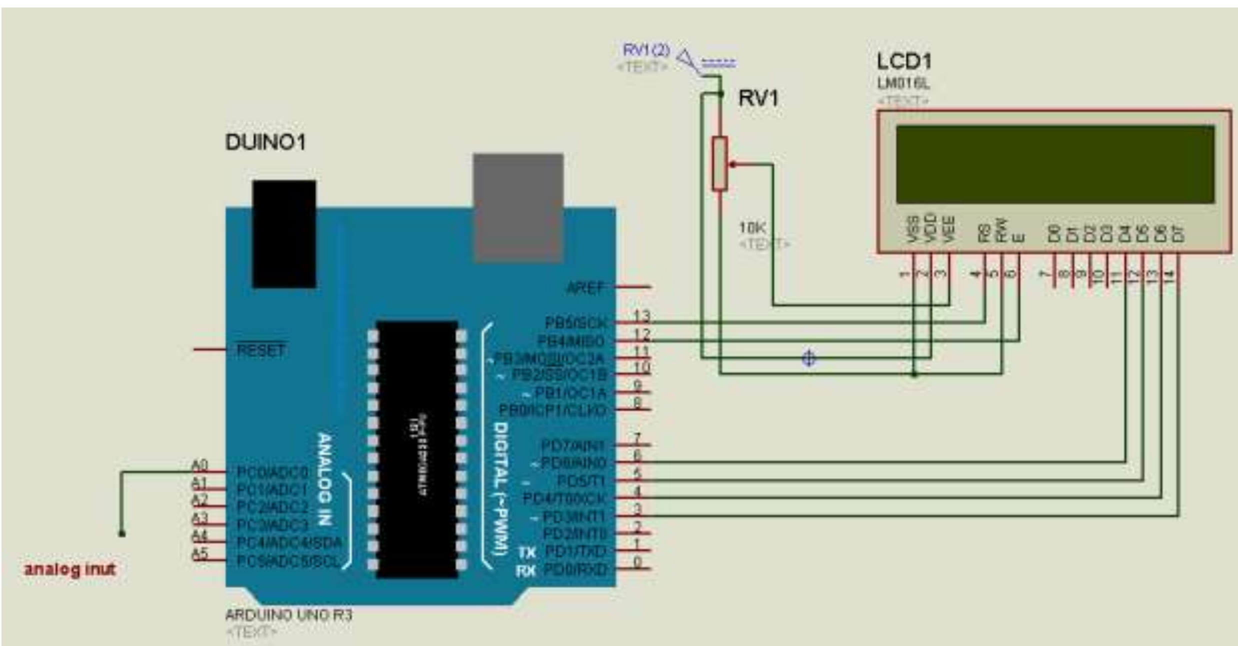

Figure B.1: Arduino and LCD Connection

APPENDIX C

COMPONENT PLACMENT AND ROUTING IN PCB

PCB ROUTING TOP

PCB ROUTING BOTTOM

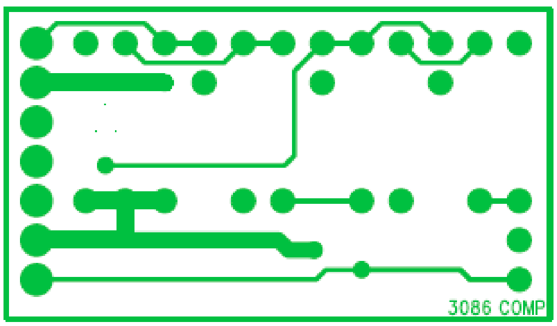

Figure C.1: PCB Routing Top

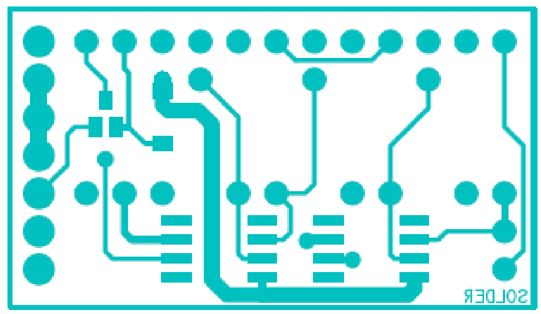

Figure C.2: PCB Routing Bottom

LAYOUT OF COMPONENT SIDE

LAYOUT OF SOLDER SIDE

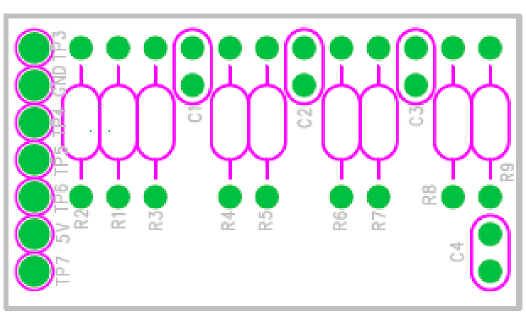

Figure C.3: Layout of Component Side

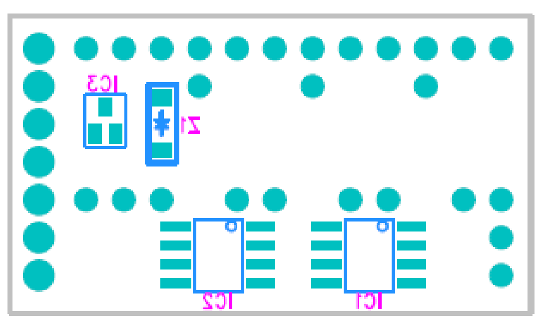

Figure C.4: Layout of Solder Side

CURRICULUM VITAE

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