PORTABLE HEART MONITORING ELECTROCARDIOGRAM DEVICE

By

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Dedication

ACKNOWLEDGMENTS

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If you are acknowledging only *one* person, change the title to ACKNOWLEDGMENT.

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EXECUTIVE SUMMARY

An electrocardiogram (ECG) machine is a medical device that monitors a patient's heart rhythm and electrical activity by placing sensors on their skin. However, these machines are expensive and not easily portable, which makes it challenging to use them in rural or remote regions of developing countries like Bangladesh due to cost and portability issues. This research paper addresses the problems of cost and portability and proposes a comprehensive solution for a low-cost, portable ECG monitoring system, encompassing the entire process from recording the ECG to generating reports for patients. This system provides real-time ECG readings on a screen, offers storage options, and calculates essential diagnostic parameters to assist doctors in making informed decisions. Such ECG machines could find applications in hospitals, homes, villages, and even disaster-stricken areas. The system described in this paper utilizes commonly available PC or laptop devices, which are now widespread, even in healthcare facilities in rural and remote areas of Bangladesh. Implementing this solution has the potential to significantly impact the fight against heart diseases.

PART-A

This part contains the concept and the project proposal as prepared on EEE400A.

Chapter 1 Project Concept and Proposal

1.1 Project introduction

One of the leading causes of human death is due to cardiovascular diseases. According to WHO data published on 11th June 2021[1], 17.9 million people die each year due to heart disease, an estimated 32% of all deaths worldwide. Less than 75% of cardiovascular disease deaths occur in low- and middle-income countries. 85% of all cardiovascular disease deaths are due to heart attacks and strokes. In Bangladesh, the risk of death due to heart disease is about 14.31%. The first step to prevent such disease is to have an effective monitoring of heart. Electrocardiography (ECG), a heart-monitoring device which is specially performed cardiology test. ECG records the electrical activity of the heart using electrodes which also senses the electrical change from the heart muscles produced by depolarizing and repolarizing during each heartbeat. The aim of the project is to make a portable heart monitoring machine a household health equipment. The target of this project is preliminary monitoring of the heart by a portable heart-monitoring electrocardiogram device.

There are a lot of people who will be able to do ECG with this product. The conventional method of doing ECG requires a lot of space and weight and it needs a continuous current source to operate. That is why conventional ECG machines are only found in hospitals and clinics. To test ECG by conventional method is also costly. Because of that many people cannot afford to do that. But portable ECG machine can be operated anywhere anytime. It is small, lightweight, and easy to operate. Every hospital, clinic, and nursing home can use this device. Even every doctor can carry one of these when performing their services outside the hospital. It is very easy to use and even every household can afford the device. Many research has been done on portable heart monitoring device. But none of them gave a complete solution which can record, monitor and generate a report. The aim of the project is to develop a portable heart monitoring electrocardiogram device that will provide a complete solution of recording, monitoring and generate a report for the people living in the rural or remote areas so that the sufferings can be minimized from any cardiovascular disease.

1.2 Literature review

A portable heart monitoring device is used to measure the electrical activity of the heart, it transforms the activity into an electrical signal and display it on a monitor [15, 16]. The traditional ECG machines are used in hospitals or diagnostic centres which are expensive and complex to use. There are different ECG monitoring or heart monitoring systems available commercially and their research works can be classified as, systems that record signals and perform analysis offline/real-time monitoring or provide real-time signal classification. There are many research works had presented portable ECG or heart monitoring system found in the literature [2-9]. Most of them concentrated on efficient recording techniques and focused on signal analysis/processing algorithms. Their research work can be divided based on detection method and data accusation method.

1. **Based on Detection Method**

3-Lead Portable ECG:

A journal about Portable ECG Monitoring System published in Modern Education and Computer Science Press (MECS-Press) by S.T.Alam, M.M.Hossain, et al [2]. In their research they worked on 3-lead ECG, where the parameters are taken from three different angles of the heart [2]. 3-lead is used on monitors one lateral, and two inferior areas of the heart. Two electrodes are connected to the chest, and one is connected to the right leg as the reference voltage. When the electrodes are placed on the skin these electrodes can detect the tiny electrical changes on the skin due depolarizing and repolarizing of the heart muscles. The electronic circuit extracted ECG signal of the heart and viewed it on a display in real-time. The signals were recorded for a minute and then digitally filtered. This was performed for offline analysis of ECG signal and after calculating detailed morphological values of diagnostic parameters which is called ECG characteristic points (PQRS) and generate a patient’s report [2]. It can monitor patient’s heart condition like heart rate, HRV, pulse rate, heartbeat rate, and RR interval.

Another research by Jeon, et al. about implementation of a portable device for real-time ECG signal analysis was published in Bio-Medical Engineering an online peer-reviewed journal [3]. They have also worked with 3-lead ECG, but they have used analog front end to reduce power consumption and ARM processor to realize signal monitoring and analysis [3].

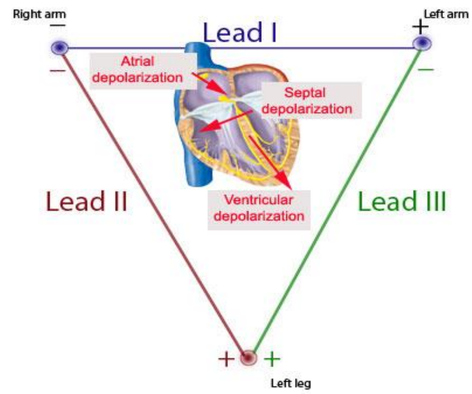


Fig. 1.1: Placement of 3-lead ECG using 3 electrodes.

12-Lead Portable ECG:

Another research on lead has been done by M.Pavani, K.Kishore using 12-lead portable ECG [4]. In 12-lead ECG the parameters are taken from twelve different angles of the heart. 12-lead is usually used on monitors anterior=front, lateral=side, inferior=back areas of the heart. In their experiment, they used 10 electrodes to take the heart's electrical activity from 12 different angles. The electrode placements are V1-4th Intercostal space to the right of the sternum, V2-4th Intercostal space to the left of the sternum, V3- Midway between V2 and V4, V4-5th Intercostal space at the midclavicular line, V5- Anterior axillary line at the same level as V4, V6- Midaxillary line at the same level as V4 and V5, RL- Anywhere above the right ankle and below the torso, RA- Anywhere between the right shoulder and the wrist, LL- Anywhere above the left ankle and below the torso, LA- Anywhere between the left shoulder and the wrist. When the electrodes are placed on the skin these electrodes can detect the electrical changes on the skin of the heart muscles. The electronic circuit extracted ECG signal of the heart and viewed it on a display in real-time. The signals were recorded for a minute and then digitally filtered. After calculating detailed values of diagnostic parameters patient's report is generated [4]. It shows the overall condition of the heart like unexplained chest pain, pericarditis, or angina, finds the cause of symptoms of heart disease, such as shortness of breath, dizziness, fainting, or rapid, irregular heartbeats, checks hypertrophied, checks pacemakers are working to control a normal heartbeat, check for high blood pressure, high cholesterol, cigarette smoking, diabetes, or a family history of early heart disease, etc.

Another research work has been done on a portable and low-cost 12-lead ECG device for sustainable remote healthcare published in 2018 International Conference on Communication Information and Computing Technology (ICCICT) [5]. In the paper the author said the research has been done using customized ECG amplifier, Digital data converting and storing units, and IoT for interfacing. Use of basic embedded and open-source tools made the system simple and easy in terms of handling.

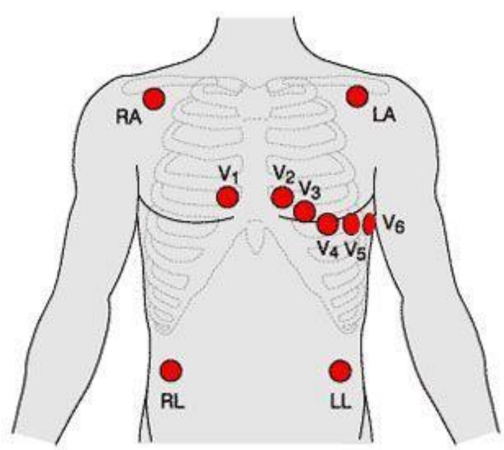


Fig. 1.2: Placement of 12-lead ECG using 10 electrodes.

Portable ECG using Microneedle Electrodes:

On May 2017 a research paper has been published in 8th Doctoral Conference on Computing, Electrical and Industrial Systems (DoCEIS) about Portable ECG using Microneedle Electrodes [6]. A microneedle is a dry electrode. It is array electrode which is coated with silver/silver chloride (Ag/AgCl). The needles can minimize the influence of the unstable and insulating stratum corneum. The microneedle electrode used without skin preparation, minimal skin trauma, low impedance, ease of operation, and high selectivity. The resistance of the conductive dermis and underlying tissues, only the coupling of the electrode and the conductive layer in epidermis is present, which is described by a half-cell potential E_{hc} and a resistor R_e and a capacitor C_e connected in parallel [7]. By using the microneedle electrodes, the accuracy of the heart signals becomes more accurate.

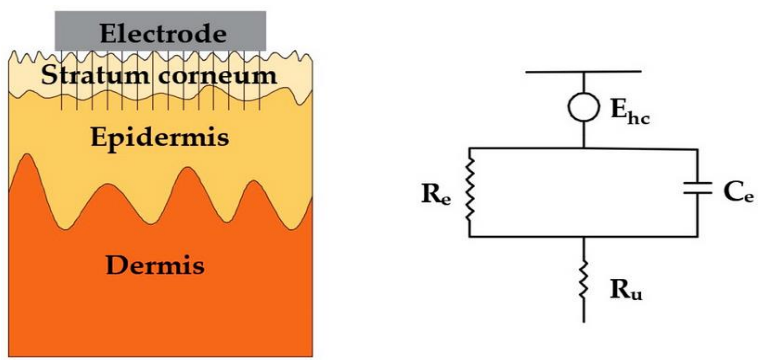


Fig. 1.3 Schematic and electrical equivalent circuit model of microneedle electrodes.

2. Based on Data Accusation

Portable ECG Monitoring System Design Using UART- WIFI Converter

This paper was published by T. Lili and H. Wei [8] where they mentioned about Portable ECG Monitoring System Design using UART-WIFI Converter. Here the main, MCU will collect data from electrodes and then process data using AFE (Analog Front-End), SD card, USB and UART-WIFI Converter. Then show the output using a real-time display. After their system debugging and detection, the overall system design showed ideal, stable performance, the optimal state power consumption, they also mentioned that the ECG waveform and heart rate value can be dynamically displayed in the local LCD and Android client, and the ECG data is locally implemented SD card storage and internet remote transmission.

<u>Portable ECG Monitoring System Design Using Bluetooth</u>

Another paper on this topic has been done by L. Kai, Z. Xu, W. Yuan, H. Suibiao, G. Ning, P. Wangyong, L. Bin and C. Hongda [9].

In reference [9], authors mentioned the use of capacitive electrode interfacing between portable heart monitoring device and smartphone. The weak ECG signals extracted from the dry electrode can be amplified, band-pass filtered, analog-digital converted and so on. Finally, it will send to the mobile phone by Bluetooth technology for real-time display on screen. The core ECG monitoring circuit is composed of a CMOS preamplifier ASIC designed by the authors which can operate steadily, precisely and display the ECG in real-time.

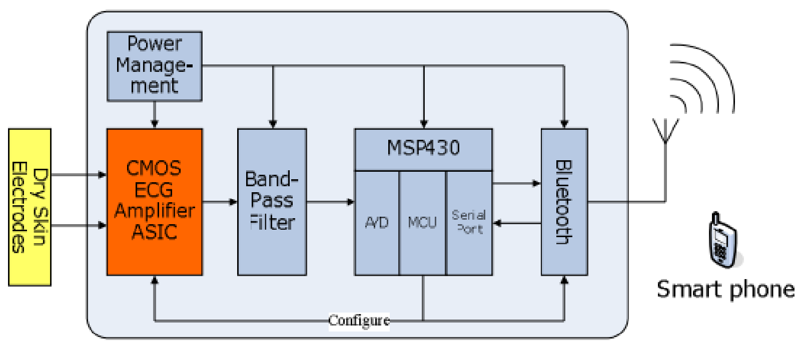


Fig. 1.4: Architecture of the ECG monitoring system.

1.3 Standards and codes of practices

Electrocardiogram (ECG) is a medical equipment used for diagnostic purposes, so standard need to establish for minimum safety and performance. According to our respective authorities (doctors, diagnostic centers), they suggest us to follow a particular standard that can be international or provided by any organization of a developed country. The American national standard for diagnostic electrocardiographic devices is followed in most of the countries including Bangladesh.

The United States Food and Drug Administration (FDA) guidance applies to most of the diagnostic electrocardiographs covered by the ANSI/AAMI EC11-1991 standard for Electrocardiographs (EC-11 standard) [10]. According to the EC-11 standard, the electrode placements of 12 lead ECG are V1-4th Intercostal space to the right of the sternum, V2-4th Intercostal space to the left of the sternum, V3- Midway between V2 and V4, V4-5th Intercostal space at the midclavicular line, V5- Anterior axillary line at the same level as V4, V6- Midaxillary line at the same level as V4 and V5, RL- Anywhere above the right ankle and below the torso, RA- Anywhere between the right shoulder and the wrist, LL- Anywhere above the left ankle and below the torso, LA- Anywhere between the left shoulder and the wrist [10].

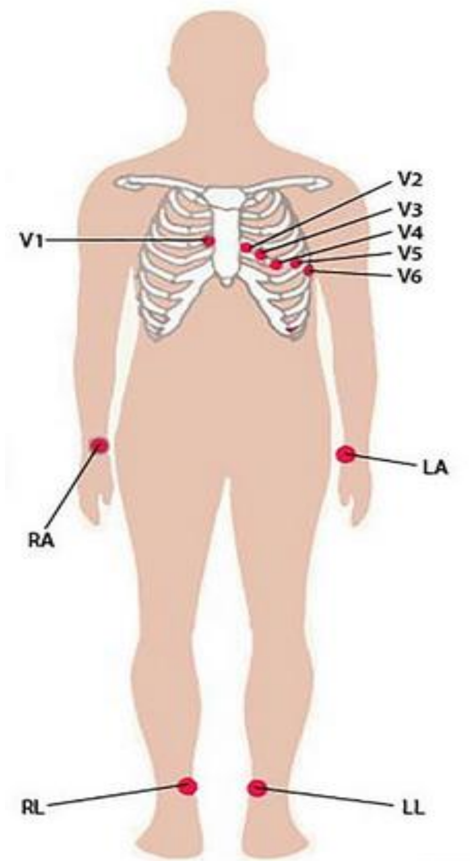


Fig. 1.5: 12 lead ECG electrode placements.

Electrode to skin impedance should be 0.62 MΩ resistor in parallel with a 4.7 nF capacitor. A single-ended input impedance should be at least 2.5 MΩ at 10Hz [10]. Direct current in patient-electrode connection shall not exceed 0.1 A [10].

There is also a standard for time base accuracy. For the time interval between 0.2 abd 2 sec the measurements error should be less than ±5% [10].

According to ANSI/AAMI EC12-2000 standard for Electrocardiographs (EC-12 standard) defibrillation voltages between ECG electrodes and the patient's body transpose up to 200 V. Up to 2% of it is absorbed by Ag/AgCl sensor electrodes [11].

For the microneedle electrode substrate should be 4 mm × 4 mm silicon wafer with a microneedle length ranging from 100 μm to 200 μm and diameters ranging from 30 μm to 50 μm [11].

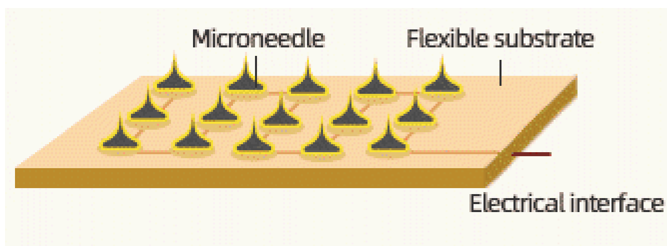


Fig. 1.6: A Microneedle array electrode.

As our device will be portable, it needs to be waterproof. According to the IP (Ingress Protection) code, the device needs IP67 waterproof [12].

1.4 Stakeholders' expectations/requirements

There are basically five types of stakeholders who are related to our project. They are:

1. Doctors
2. Diagnostics center
3. Cardiac patient
4. Caretaker of Cardiac patients in family members.
5. Caretaker of Cardiac patients Nurses.

We have surveyed many cardiac patients which are 40% of our total survey, caretaker of cardiac patients 30%, doctors are 15%, nurses 7% and diagnostic centers 8% a total of 100% of our survey.

A general feedback we get from cardiac patients, caretaker of cardiac patients and nurses that can be summarized like this:

A cardiac patient needs to do ECG test 12 to 24 times in a year, and it cost more than Tk12,000. Most of our stakeholders show the necessity of a portable heart monitoring electrocardiogram device. Their expected price for our device is Tk8,000 to Tk12,000. Also, our device will last longer than at least 2 years. If the device can be maintained properly then we expect that the lifetime of the device will increase. Majority of people we surveyed preferred rechargeable battery and also they preferred built-in display on the device. We can predict that our device price will be around the expected price of our stakeholders.

We initially approached doctors and diagnostic center with portable ECG device. They gave their valuable feedback which can be summarized as:

1. Cardiac disease is increasing rapidly, and initial monitoring of heart can save a life. So, they show the necessity of the device.
2. They also suggest to use dry electrodes as most of the patients will not agree to put gel and gel may feel itching.
3. In number of lead they preferred 3 lead or 12 lead

We also asked doctors for the standards and codes of practice, and they suggest us to follow any international or developed country’s standards.

1.5 Project requirements

After the survey from the stakeholders, we have got their requirements such as portability, battery type, built-in display etc. We will address those points as project requirements for our project. They are:

1. Portable Device: Traditional ECG devices are very heavy and complicated. It cannot be carried anywhere. To monitor one's heart condition they need to go to a hospital or diagnostic centre. This is where our product comes. We will try to build a portable heart monitoring device that can be carried anywhere anytime. Our stakeholders also want it to be portable so that the device can be carried around any place. This will help them to check their health anytime at any place.

2. Built-in Display: Display is one of the main parts of this device. Display will be used to show the output. But a display can be added in different ways. One of them is built-in display into the device. From our survey we saw that most of our stakeholders wanted a built-in display. A built-in display will be used to show the relevant information regarding heart. This will be handy to use.

3. Rechargeable Battery: Our stakeholders mentioned it to be rechargeable and lightweight. This demand came from every type of stakeholders. Rechargeable batteries are staple for any kind of electronic device. Hence, it is safe to say that a portable device will also be powered by rechargeable batteries. So, in our device we will include rechargeable batteries.

4. Dry Electrode: Electrode is the most important requirement in our project. It contains sensors and those sensors will pick up the signals and pass to the microcontroller. According to the feedback from stakeholders, we decided to use dry electrode. Sometimes wet electrodes can create allergies or other skin problems. So, we take this decision to use dry electrodes.

Here we discussed about requirements from our stakeholder’s feedback. Now we’ll discuss about few more technical side requirements. They are:

a) Frame: As our device will be a portable device so we need a frame to set our product structure on it. The frame will make it easy to carry anywhere. Also it will protect the circuit from any kind of unwanted incidents.

b) Microcontroller: A microcontroller will be the heart of this device. Without a microcontroller the whole operation cannot be controlled. A microcontroller will be required for this project to perform its specific task. The microcontroller will receive the data from electrodes and it will analyse and perform its task and after that it will generate a result which will be sent to the display.

c) Instrumentation amplifier: Instrumentation amplifiers are used in different applications where it is necessary to remove any unwanted signals. For our portable heart monitoring device the instrumental amplifier should be compact, lightweight, and consume as less power as possible. Specialized instrumentation amplifier will be used to convert relatively weak electrical signals for monitoring purpose.

d) DC voltage regulator: A voltage regulator is a component of a power source that makes sure the voltage supply is uniform and steady under all functioning situations. During power failures and changes in load, it controls voltage. For our device we will use a dc voltage regulator. To ensure device performance a steady voltage is required. A dc voltage regulator will give us the exact same thing.

e) Active low-pass filter (LPF): Active low-pass filter will be used for filtering unwanted noise inside the signal. ECG data is not noise free. Power line interference, electrode contact noise, instrumentation noise, electrosurgical noise are some of them. Those noises cannot be kept for a clear reading. So, this noise must be removed. And for that an active low pass filter is needed.

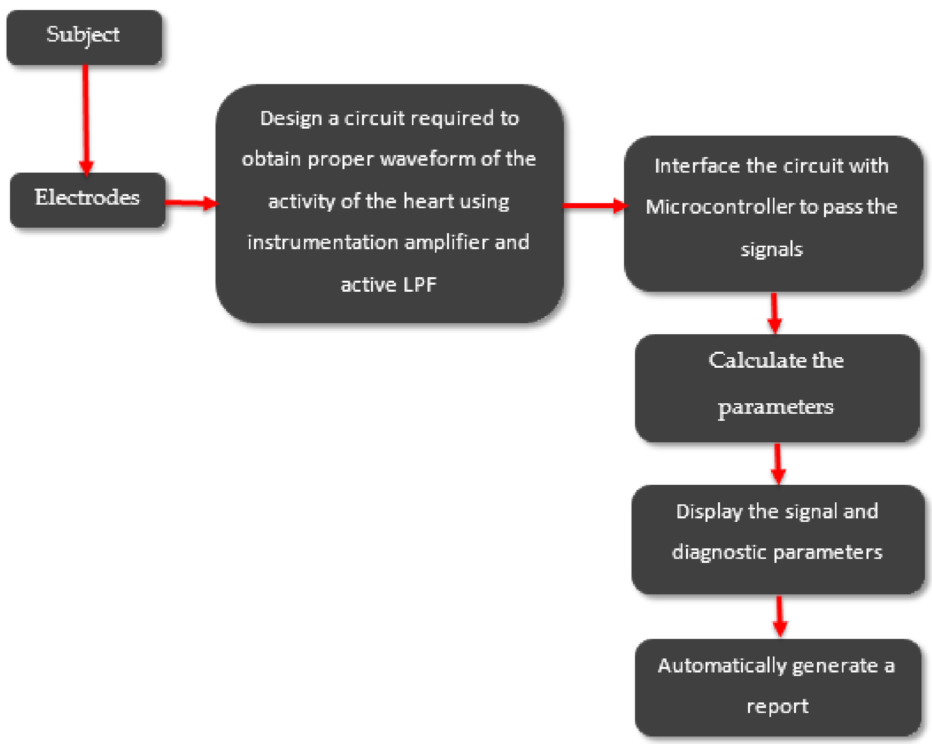


Fig. 1.7: Work flow diagram

1.6 Project Management

1.6.1 *Project plan*

We have identified all the activities that we need to complete in the whole project. We have sorted the activities in sequential order. All the activities with their completion time and milestones are represented in the table below.

Table 1.1 Project Activity List

Activity No.	Activities	Duration (Weeks)	Predecessor	No. of Worker
PART-A				
1	Topic Selection	1	-	4
2	Topic finalization from supervisor	1	1	4
3	Literature review and research	3	2	4
4	Identifying the stakeholders and preparing questionnaire for the stakeholders and collecting response from stakeholders via survey question [Milestone-1]	2	2,3	4
5	Finalizing the project requirements	1	4	3
6	Reviewing standards and codes of practice	1	5	3
7	Preparing project plan [Milestone-2]	1	4,5	2
8	Preparing risk assessment	1	7	3
9	Identification of project impact	1	8	2
10	Preparing budget and analysis of product lifecycle [Milestone-3]	2	8,9	4
11	Preparing project report and submission [Milestone-4]	3	3, 6, 9 and10	4
PART-B				
12	Initial design of the project	3	11	4

13	Analyzing of alternate solution and selection of the suitable one [Milestone-5]	3	12	4
14	Cost optimization	2	13	4
15	Verification of initial design and refine the design	3	13,14	4
16	Preparing project report and submission [Milestone-6]	3	15	4
PART-C				
17	Equipment purchase	2	16	3
18	Prototype development [Milestone-7]	4	17	4
19	Performance evaluation	2	18	4
20	Finalization of the design [Milestone-8]	2	19	4
21	Preparing bill of materials cost of solution	1	20	3
22	Economic analysis [Milestone-9]	1	20,21	3
23	Preparing final report and presentation [Milestone-10]	3	22	4

Gantt chart

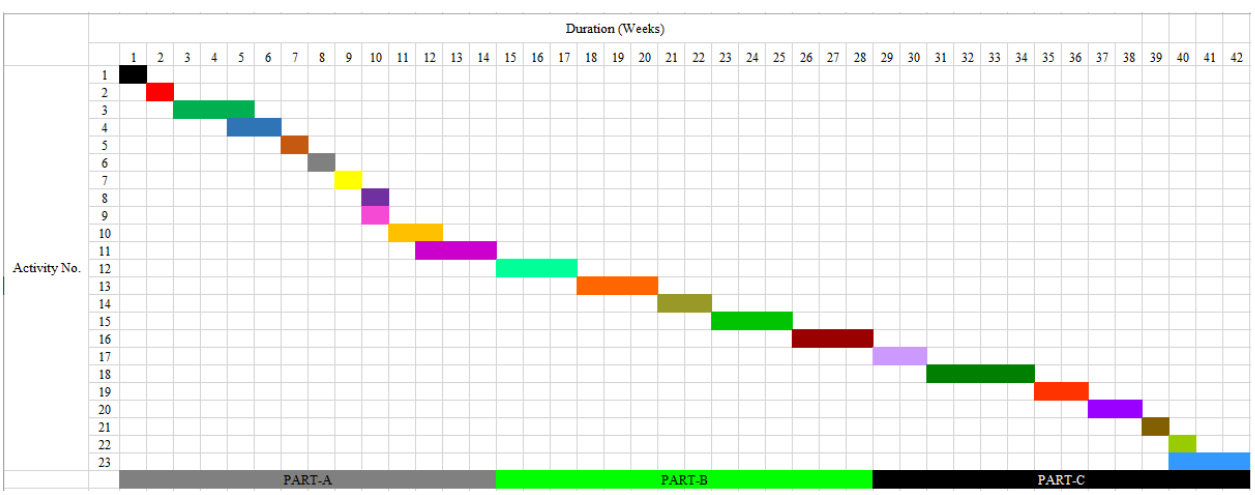
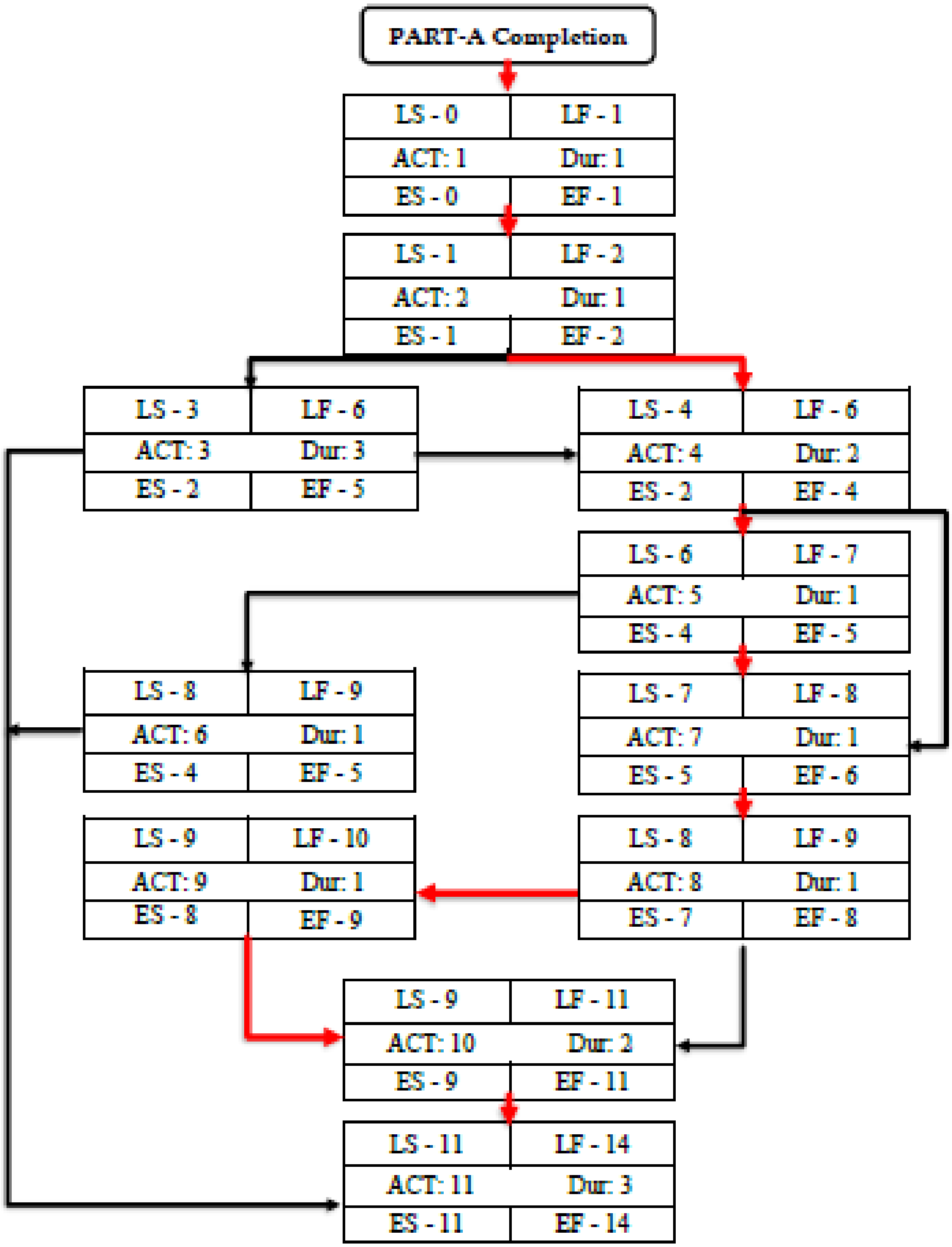
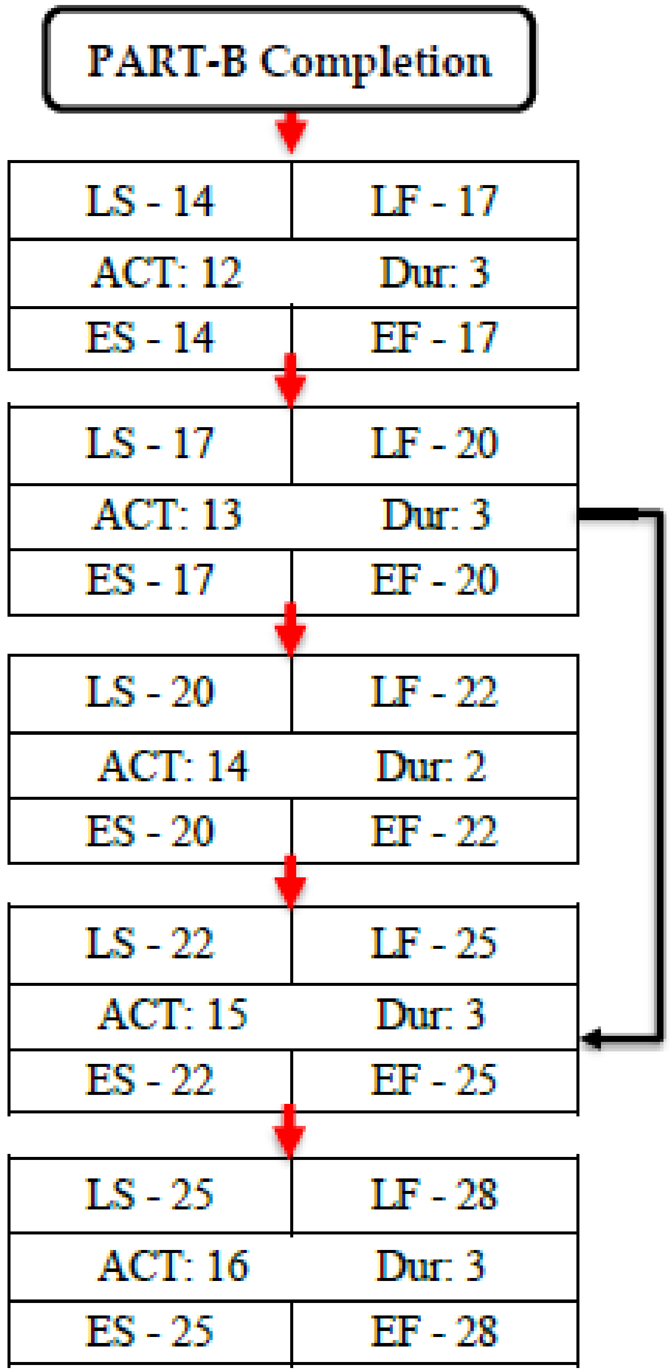


Fig. 1.8: Gantt chart

Critical Path Method (CPM) Diagram




PART-B Completion
LS - 14
LF - 17
ACT: 12
Dur: 3
ES - 14
EF - 17
LS - 17
LF - 20
ACT: 13
Dur: 3
ES - 17
EF - 20
LS - 20
LF - 22
ACT: 14
Dur: 2
ES - 20
EF - 22
LS - 22
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Dur: 3
ES - 22
EF - 25
LS - 25
LF - 28
ACT: 16
Dur: 3
ES - 25
EF - 28

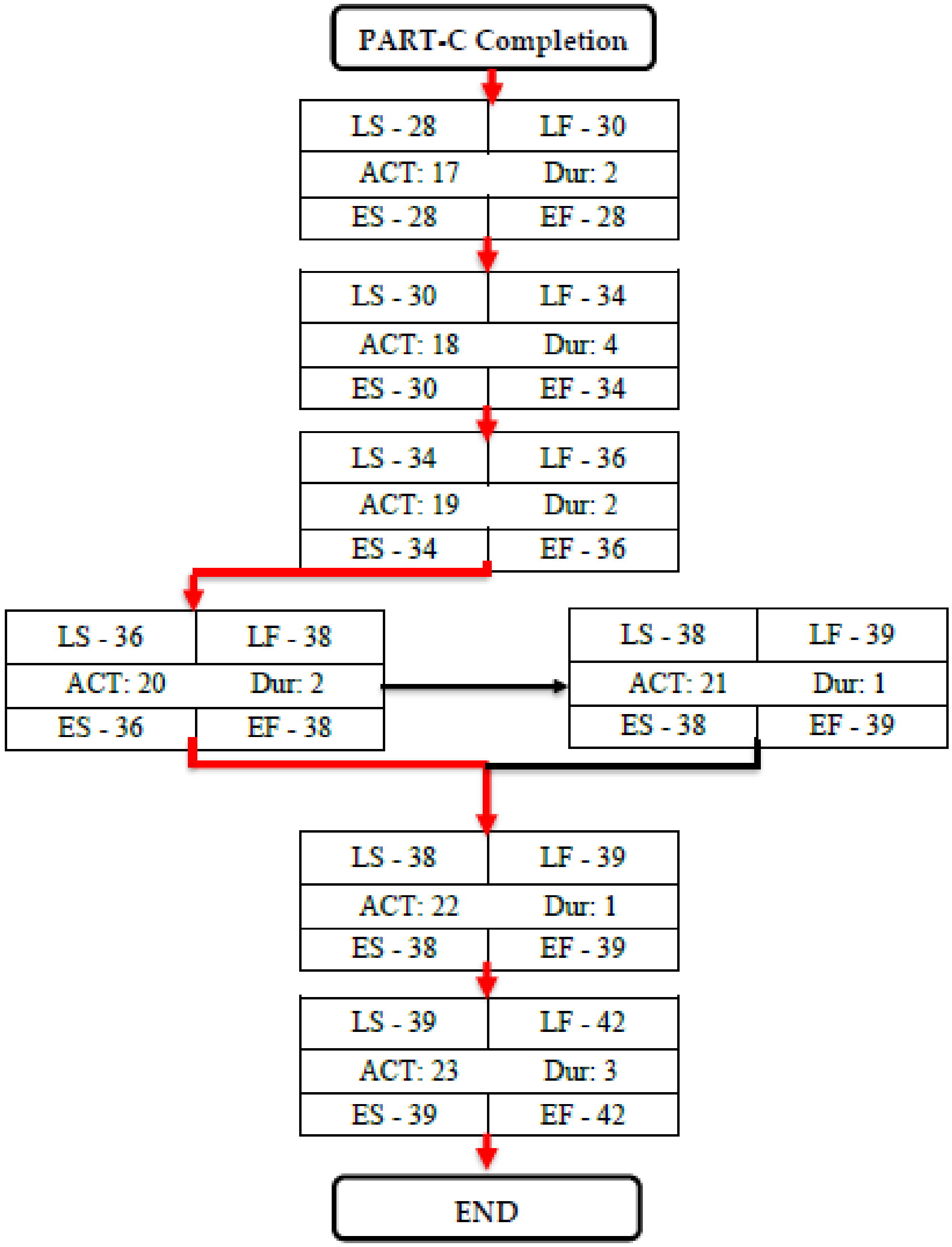


Fig. 1.9 Critical Path Method (CPM) Diagram

Critical Path

Critical Path: 1-2-4-5-7-8-9-10-11-12-13-14-15-16-17-18-19-20-22-23

Project Completion Time: 42 Weeks

Critical Path Method (CPM) Attributes:

- Act – Activity
- Dur – Duration
- LS – Late Start
- LF – Late Finish
- ES – Early Start
- EF – Early Finish

1.6.2 *Risk management*

Any part of this project can involve various types of risks. Decision & risk management is important to ensure project completion on time. Risk analysis and mitigation and prevention strategies are important. Identify and control potential project problems. When potential risks are identified at the beginning of the project, we can take the necessary measures to minimize those auspicious times. In our project we also identified several potential risks which may bring negative impact on our project. We have also identified these mitigation and prevention measures strategies.

Resource unavailability:

The project required both electrical, mechanical, and biomedical equipment. As a result, many of these components may not be available online. But this global economic problem has made the situation dangerous. Most recently, due to the spread of the new coronavirus. It is very difficult in this situation because the price of the product may increase. Overall costs and global economic issues are also impacted by increased transportation, which can lead to higher product prices. And because of that we may not be able to get any particular item right on time. It could be unavailable to us.

Technical difficulties:

During the prototyping process, many technical difficulties may arise. The request may not be met, component failure may occur, or faulty resources can be identified during execution. So, it takes more time to identify errors or modify the system. Also, due to global economic problems, it may not be possible to immediately go to the market to change the device or buy a new one. Because of that reason, a delay may also occur.

Software simulation risk:

We will design our entire project using simulation software. If some specific characteristics that required for our project are not included in the selected software, there is a risk to project design. In addition, if the software publisher stops providing the services of our chosen software, it will also be a potential risk for this project. Our project design Initialization may be delayed due to these risks, which will affect our 4th milestone. To reduce these risks, we will have to use alternative software. Also, if we can't find data or information specific to our project in any software, that could be a risk for our project.

Mitigation plan:

To complete milestones on time, tasks must be completed on time. If each task is delayed due to uncertainty, we can proceed to the next task if we have not completed the required previous tasks. When the situation makes it easier to complete the identification task, then we can do it. This will help us complete milestones on time. If we have a task that is late and the next task must be completed ahead of time to make up for the delay, we can work in parallel. By splitting the whole group into two parts, we can do two tasks at the same time. Due to the lack of resources available, we also need to access the online platform of the local market. Also, all resources can be purchased at once, saving both time and money. Recovery technical issues may require system modifications and may delay tasks. In this amount of time, we can work in parallel to complete in time. In some cases, we can work separately, and we can be responsible for modifications or repairs.

Contingency plan:

Sometimes situations can become more important. We may have to complete a certain task to move on to the next task. In such a situation, we may be faced with some delays in completing tasks as well as milestones. Then we may need to fix the project plan to complete the part of the project on time. Due to our regular activities, courses like exams can also make parallel work important. Meanwhile, we can continue to work as a member for a certain time, then another member can start with the next one. Arrive and adjust over time when purchasing equipment and deploying prototypes. It will save our shopping time. This can be very important in this situation, but we must consider completing the project on time. After all, some quests can still be delayed and delay the timeline. We must review the plan again to catch up with time. Besides that, some people have an allergy to electrodes which can make this project risky for us.

Financial risk:

This is another project risk for us. Sometimes we need to buy equipment related to the project, but we don't have the money, so we can't buy the product at that time. It also slows down our project time.

1.6.3 *Required resources and budget*

We will need to have an estimate of what resources and budget we will need to complete the project. As the project is currently in 400-A state, it will not be possible to give an exact value. So, we will have to assume and estimate things as there are too many unknowns at his moment.

Resources:

1. Computer (Up to date computer is needed as heavy software will be run on the machine)
2. Software:
   - i) MATLAB
   - ii) Arduino IDE
   - iii) Proteus
   - iv) PSIM
   - v) ECGSIM

4. Soldering apparatus
5. Electrodes
6. Frame
7. Electronic Parts
    i) Dual DC voltage regulator
    ii) Microcontroller
    iii) Instrumentation amplifier
    iv) Active low-pass filter
    v) Display
    vi) Clamper
    vii) Battery
8. Digital multimeter

Project Budget

Table 1.2 Project Budget

No.	Equipment	Unit price (Tk)	Quantity/Amount	Total (Tk)
01.	Electrodes	25	12	300
02.	Frame	200	1	200
03.	Soldering Kit	1000	1	1,000
04.	Digital Multimeter	1200	1	1,200
05.	Microcontroller	1000	1	1,000
06.	Dual DC voltage regulator	500	1	500
07.	Instrumentation amplifier	700	1	700
08.	Active low-pass filter	800	1	800
09.	Display	1000	1	1,000
10.	Battery	150	2	300
11.	Transportation and communication			1,500
12.	Others			1,500
	Total			10,000

1.7 Projected product lifecycle

This is very important to create a durable product. It was also a request of a group of stakeholders. When we design the solution, we must maintain technical principles as well as stakeholder requirements. When the prototype is implemented, we will focus on product sustainability. After implementation, product maintenance and services are the most important part. We can take responsibility for maintenance over some time. We also undertake equipment repairs and modifications. without interfering. A wide variety of devices is required for system construction. Replacing the device is not difficult as it is available on the local market. Also, the mechanism is simple and easy to understand, so no expert is required to fix our system. A maintenance team can be appointed or used part-time or by third-party workers. Maintenance and repair training is provided as needed by the repair team. For foreign workers, this can be done at our company or by trained or qualified employees directors. We may need to clean our system as dust can damage it. In addition, it must be properly managed to ensure the safety of the system. To further improve the system, we can continue our research to improve the performance of the system. In the future, the product could be updated, we can add built in display into this device for further development. In future we can build mobile app to interface with the device so that the user can control the device from their phone. They can also see the output in the same application.

1.8 Impacts of the project

1.8.1 *Impacts on society*

According to the World Health Organization (WHO), every year around 17.9 million peoples die because of heart diseases [13]. Among those 90% of people dies because of heart attacks and strokes. Most importantly our generation is at highest risk for heart diseases. Because of our lifestyle and eating habit, our health condition is not very good. Most of us do not eat healthy food. Also, we do not live in a healthy environment. So, it is obvious that our heart will not be in very good condition. Because of that anytime we can face heart attacks, strokes, or any other heart problem. In that moment of emergency, a portable heart monitoring device can be a lifesaver.

For initial checkup a portable heart monitoring device can save hundreds of lives. When a person faces any heart problem, they get panicked. They cannot decide whether they should go the hospital, or they should stabilize first. If they do not do the checkup right time, sometimes it can lead critical patient to death. If they have a portable device that can checkup their heart condition, then they can be sure what steps need to take. That is our final goal of this project to help people monitor heart from anywhere anytime. This will be able to save more lives. Also, if this product can be mass-produced then there will be a lot of job opportunities for young and unemployed people. This can be a huge impact on a society like us where unemployment is a big issue. Through our project, we can have a great impact on the society.

1.8.2 *Effects on environment and sustainability*

There are not many environmental impacts exists of our product. This is an environment friendly product which can be used on household. But still there is some effect on the environment. Mainly the problem will create the electrodes. Our electrodes will be reusable but still it needs to be replaced after using few times. If the used electrodes could not be recycled, then it could have huge down impact on our environment. Maximum electrodes are made of plastic. And we all know how dangerous plastic can be for soil and water. Plastic does not decompose. It remains as it is. If the plastic electrodes are left here and there, then there will be soil pollution, water pollution. Plastic also releases toxic substances when it is exposed under sunlight. This can also pollute air heavily. If the electrodes are not recycled properly and people decided to burn it then by burning it pollutes the air heavily. This is not only for electrodes but also for any plastic part that's present in the product. So, to prevent this from happening, everyone should be very careful about the electrodes while disposing. It is better if it could be recycled. Then the bad environmental impact can be minimized.

Another one is after the lifecycle of the product it needs to be demolished. The whole product will be made of electronic materials. Circuit, microcontroller, amplifier, voltage regulator, battery all of them contains toxic substances. If these does not handle properly then these toxic substances can harm our environment on a huge level. If these substances left anywhere, it would get mixed with soil, water. If that happens soils will not produce any crops, fishes on water will die. Eventually it will get mixed with our foods. This will also have very bad impact on our health which is very bad since our products goal is to keep people healthy from danger. So, to keep the environment from more damage we should bring awareness to people about how to use and dispose the product more effectively and environment friendly way. Only that way these all can be stopped from happening.

1.8.3 *Health and safety issues*

Our whole project is based on human health. Our priority is to bring down the possibility of death by heart diseases through our project. Our portable heart monitoring device will detect current heart condition and will give the feedback. Although the risk associated with this device are very low but there are still some things that can be an issue for human health.

The main issue can arise when people need to put the sticky electrodes on their skins. Some peoples may feel very uncomfortable with that. Also, the electrodes may break down tissue or irritate the skin if they are applied for an extended period of time [14]. Also in some situations like pregnancy, this device should be used carefully. Some people think electrocardiogram devices emit radiation. But this is completely wrong. These kinds of devices are fully safe for human health.

Our device will use rechargeable battery as its power source. Due to charging problem in the device human health can be at high risk. Because of battery mismanagement, there may be a possibility of increasing battery temperature and also fire hazards, by which human health can be suffered. Also, if the casing does not made properly there is a possibility of interaction with water with internal circuit of the device. If that ever happens there could be serious health damage.

And finally, this is an electronic device. This device should be handled carefully. This should be kept in a safe place, away from water and children. If it can be handled carefully then health damage should be bare minimum.

PART-B

This part includes the design, analysis and optimization of the project as prepared in EEE400B.

Chapter 2 Project Design

2.1 Functional design

The major requirements of our project are described below briefly:

1. Our main purpose is preliminary monitoring of the heart to record the heartbeats and get the health status within a few times.
2. We'll use a built-in display so the result will be visible on that display.
3. Also this project is targeted to be portable, so that users can carry this device easily anywhere at any time.
4. According to the feedback of stakeholders, try to build the device user-friendly and waterproof. This device must have a rechargeable battery which has enough capacity to run the display for at least a certain amount of time.
5. Considering the other requirements, we'll use dry electrodes to avoid any kind of skin allergy problems.
6. There is one standard for time base accuracy. For the time interval between 0.2 abd 2 sec the measurement error should be less than ±5% [10].
7. Electrode to skin impedance should be 0.62 MΩ resistor in parallel with a 4.7 nF capacitor. A single-ended input impedance should be at least 2.5 MΩ at 10Hz [10].
8. Direct current in patient-electrode connection shall not exceed 0.1 A [10].
9. According to ANSI/AAMI EC12-2000 standard for Electrocardiographs (EC-12 standard) defibrillation voltages between ECG electrodes and the patient's body transpose up to 200 V. Up to 2% of it is absorbed by Ag/AgCl sensor electrodes [11]
10. The microneedle electrode substrate should be 4 mm × 4 mm silicon wafer with a microneedle length ranging from 100 μm to 200 μm and diameters ranging from 30 μm to 50 μm [11].
11. Often, the materials used to create the device are recyclable and environmentally beneficial.
12. Extra hot and humid environments should be avoided.

Functional Block Diagram:

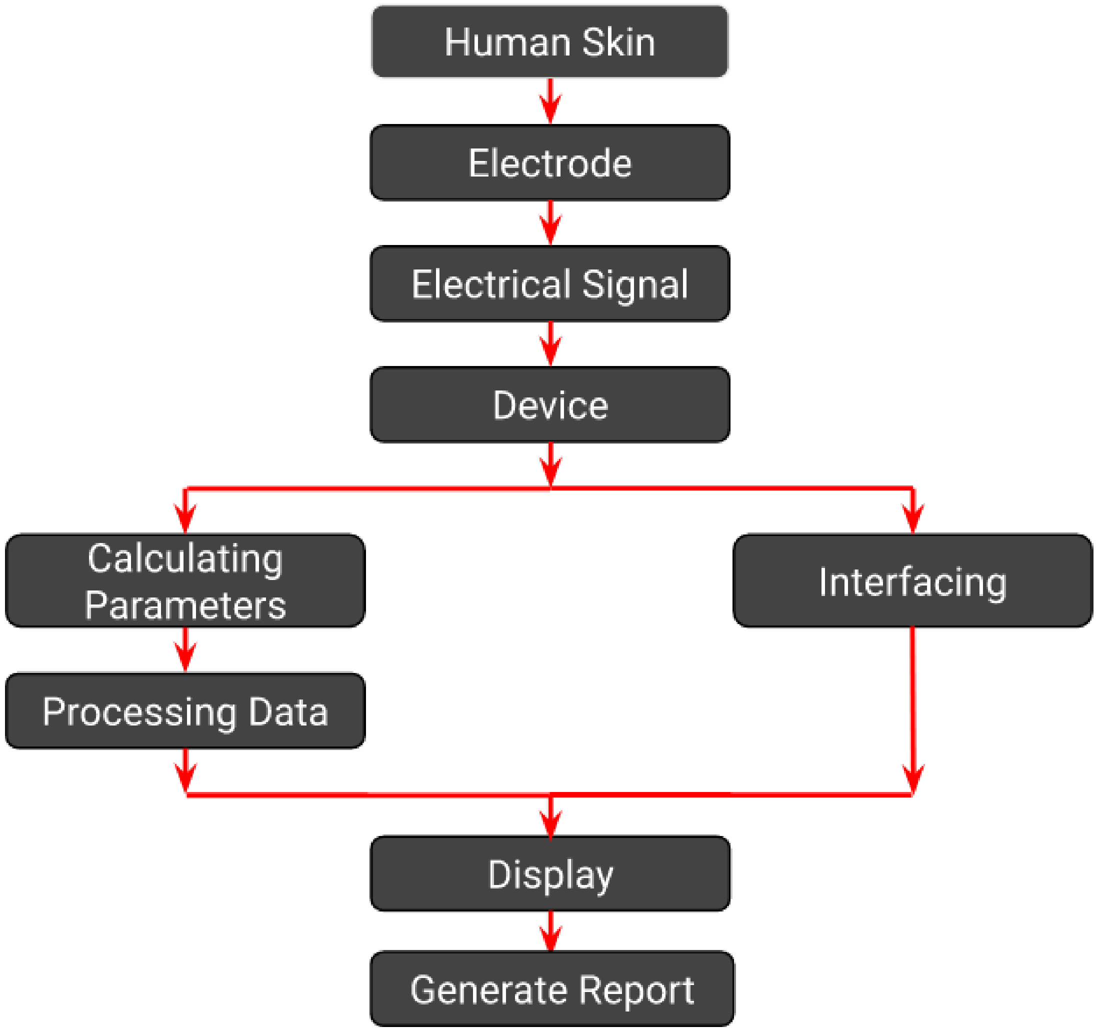


Fig. 2.1: Functional Block Diagram

Technical Specification:

Human Skin: Human skin can be an important source of data for heart rate monitoring systems. The skin contains numerous blood vessels that carry blood to and from the heart, which can be used to measure heart rate. One of the most common ways to collect data from the skin for heart rate monitoring is through the use of electrode sensors. Typically, these sensors are placed on the skin of the finger, wrist, or chest.

Electrode: From the heartbeat, Electrode will sense the signal of the heart. The electrodes are connected to the ECG machine by wires, which transmit the electrical signals from the heart to the machine for analysis. The placement of the electrodes is important because it determines the accuracy of the ECG signal. During an ECG, the electrodes detect the electrical activity of the heart muscle as it contracts and relaxes. This electrical activity is then displayed on the ECG machine as a series of waveforms, which can be analyzed by a healthcare provider to determine if the heart is functioning properly. Electrodes are designed to detect and measure electrical signals.

Electrical Signal: The Heartbeat will convert to electrical signals. The electrical signals detected by electrodes are generated by the movement of charged particles, such as ions, within the body's tissues. In the case of the heart, the movement of ions through the heart muscle during each heartbeat generates electrical signals that can be detected by electrodes.

Device: The device typically has two or three electrodes that are placed on the skin of the chest, and sometimes on the limbs, which pick up the electrical signals produced by the heart. When the electrodes detect a signal, they send it to the device's microprocessor, which processes the signal and displays it as a waveform on a screen or records it for later analysis.

Calculating Parameters: This section will calculate the necessary data for giving accurate data for heart rate.

Interfacing: Interfacing in an ECG machine refers to the process of connecting the machine to a computer or other electronic device to transfer and analyze ECG data.

Processing Data: The raw data collected by the ECG machine is typically a series of electrical waveforms that represent the electrical activity of the heart over time. The processing of this data can involve several steps, including filtering, amplification, and analysis. An amplifier is needed to extract the ECG signal by eliminating the noise. A low pass filter is needed to eliminate high frequency noise from the ECG signal.

Display: The device will process the signals and display them on the screen as a graph that shows the electrical activity of the heart over time. The display typically shows multiple leads or channels that provide different views of the heart's electrical activity, such as the rhythm and timing of the heartbeats, the strength and direction of electrical signals in different parts of the heart, and any abnormalities or irregularities in the heart's electrical activity. The display may also show other information such as the patient's name, age, and other vital signs like heart rate and blood pressure.

Generate Report: To generate a report from a portable ECG, the device records the electrical activity of the heart and stores it for analysis. Once the monitoring period is complete, the data can be downloaded and processed to generate a report that includes information about the heart's rhythm, rate, and other characteristics.

2.2 Analysis of alternate solutions

The design process of our project is mainly divided into two parts. One is based on a detection method. Here, in the detection method, we can divide it into subsystems that are based on lead and based on electrode sensors. Lead is basically the angle of detection where signals will be taken from different angles of heart. The second method is based on data accusation.

Based on detection method:

Based on the detection method our portable ECG device can be divided into 4 parts, 3 lead system, 5 lead system, 7 lead system and 12 lead system. We have discussed the basics of 2 systems in the literature review part in Part-A. Which are: 3 lead system and 12 lead system. We did not discuss about 5 lead system and 7 lead system in Part-A. But for Part-B we have decided to add those two systems also as we will do the simulation for all 4 of them. So, here we will discuss those 4 systems in more detail. For the simulation we have used some components a little description of them are given below.

Instrumentation Amplifier:

An instrumentation amplifier is one kind of IC (integrated circuit), mainly used for amplifying a signal. An instrumentation amplifier is used to amplify very low-level signals, rejecting noise and interference signals. Instrumentation amplifiers can be used where high levels of accuracy and both short- and long-term circuit stability are needed. Examples include things like temperature, blood pressure, earthquakes, and heartbeats.

For our project we have used an instrumentation amplifier to amplify the heartbeat of a person. As we know the electrical signal, we get from the human body has a very low amplitude which needs to be amplified. Otherwise, we will not be able to measure or calculate our desired result.

For an instrumentation amplifier gain calculation is very important. Also, for our project we need to calculate the gain of the instrumentation amplifier. The gain of an instrumentation amplifier in an ECG circuit indicates the extent of amplification used to the ECG signal in order to produce an accessible output. Since the ECG signal is amplified more with a higher gain, the amplifier is more sensitive, and the measurement is more precise. Engineers can modify an amplifier circuit's gain with the use of an instrumentation amplifier without having to modify the values of several resistors.

For this reason, an instrumentation amplifier is more suitable for our design.

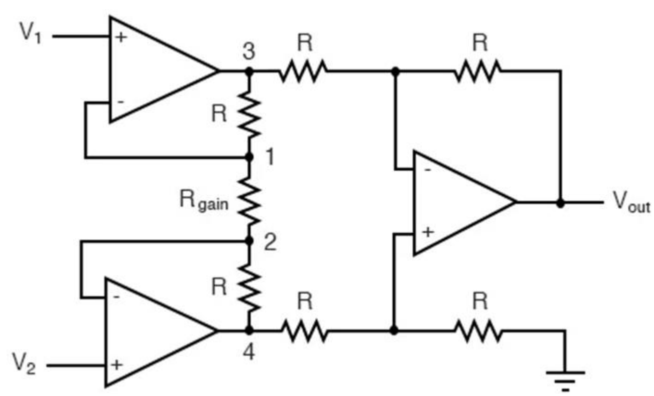


Fig. 2.2: An instrumentation amplifier

Instrumentation Amplifier Gain Calculation:

Gain, $A_v = 1 + \frac{2R_2}{R_{Gain}}$

Summing Amplifier:

Summing amplifier is basically an op amp circuit that can combine numbers of input signals to a single output that is the weighted sum of the applied inputs. Summing amplifiers are a type of inverting amplifier. In an inverting amplifier there is only one voltage signal applied to the inverting input. But if we connect a number of input terminals in parallel to the current input terminals, then this inverting amplifier can easily be converted to a summing amplifier.

For our particular designed circuit we have used 3 instrumentation amplifiers to represent different leads. We have used a non-inverting summing amplifier to combine those different leads into one single output.

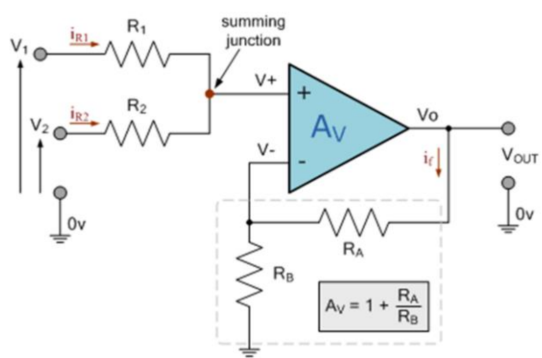


Fig. 2.3: Non-inverting summing amplifier

Low pass filter:

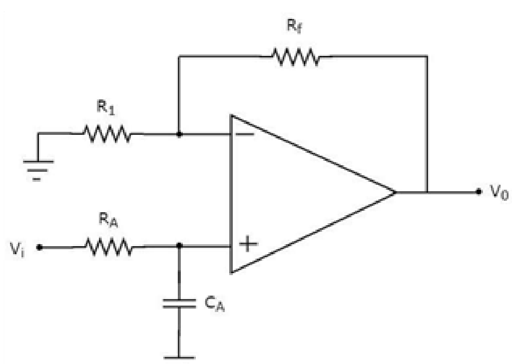


Fig. 2.4: Low pass filter

A second-order active low pass filter was implemented to improve the frequency response of the ECG signal by removing high frequency noise. This was done to enhance the quality of the ECG waveform. One of the common types of noise that can affect biomedical recordings is power line interference, which comes from the power supply frequency of 50Hz and its harmonics. To eliminate this unwanted electrical interference, a digital finite impulse response (FIR) low-pass filter is applied to the original ECG signal [2].

For cut-off frequency of second order low pass filter formula is given below,

$$fc = \frac{1}{2\pi\sqrt{R32\ R33\ C2\ C3}}$$

Non-Inverting Amplifier:

A non-inverting amplifier is an electronic circuit that amplifies an input signal without changing its polarity. It is called "non-inverting" because the output signal has the same polarity as the input signal. The basic circuit consists of an operational amplifier (op-amp) with two resistors connected to its inverting (-) and non-inverting (+) inputs, and a feedback resistor connected between the output and the non-inverting input. The input signal is applied to the non-inverting input, and the output signal is taken from the output of the op-amp.

For our project, we are receiving a signal from an Arduino Uno, and also using a summing amplifier to amplify the signal. However, we need to send this signal to an Arduino Nano, as it is too low-powered to be detected properly without amplification.

To amplify the signal, we are using a non-inverting amplifier, which takes the input signal, amplifies it, and outputs a larger version of the same signal without reversing its direction. This circuit uses an op-amp and a feedback loop to ensure that the voltage at the non-inverting input remains proportional to the input voltage, resulting in a larger output signal. By changing the ratio of resistors in the feedback loop, we can easily adjust the amplification level. Once the signal is amplified, the Arduino Nano can detect it and display the output in a virtual terminal.

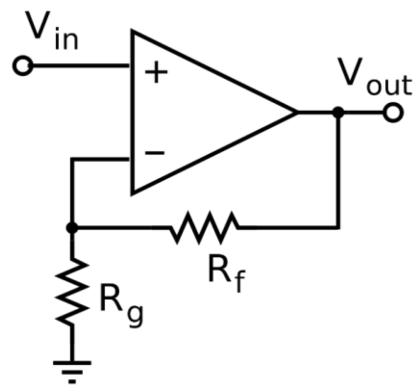


Fig. 2.5: Non-inverting amplifier

Explanation of Threshold for detecting R peak:

The threshold in an ECG (electrocardiogram) is typically used to distinguish between noise and signal. Adjusting the threshold can help to improve the accuracy of ECG analysis. The threshold value of applied ECG signal depends on the incoming signal, average high amplitude peak can be labelled as an R peak [20].

$T = V + c * \sigma$

where T is the threshold voltage, c is a constant that determines the sensitivity of the threshold, V is the DC offset or baseline voltage, and σ is the standard deviation of the noise or interference in the ECG signal.

Here, we set c = 0.25 which is used for searching for missing R-peak, thresholds are reduced by 0.25 to avoid missing beats.

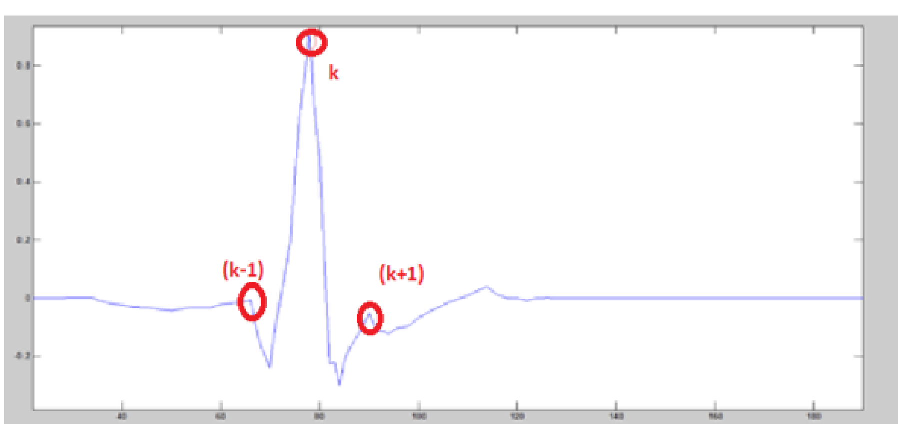


Fig. 2.6: Explanation of Threshold for Detecting R Peak

where, k is the sample where R-peak is present, k+1 and k-1 are the exceeding and preceding samples of k sample respectively.

A minimum value is set in the amplitude range of R-peak as the "threshold". Particularly for R-peak detection, the value of threshold is 0.4 - 1mV [20].

ECG data input:

Fig. 2.7 : Arduino UNO

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It includes a microcontroller board and a software development environment for writing, compiling, and uploading code to the board.
For the simulation, Arduino is used as human body. Three lead actual ECG digital data, was taken from a publicly available GitHub repository[22], has been given in Arduino code as input. Output of digital data is coming from pin 10, 11, 13.

Fig. 2.8 : 12-bit digital-to-analog converter (DAC) chip

The digital data coming out from Arduino passes through MCP4921. It is a 12-bit digital-to-analog converter (DAC) chip. It is used to convert digital signal to analog signal.

3-Lead Portable Heart Monitoring System:

3-lead ECG, where the parameters are taken from three different angles of the heart [2]. 3-lead is used on monitors one lateral, and two inferior areas of the heart. Two electrodes are connected to the chest, and one is connected to the right leg as the reference voltage. When the electrodes are placed on the skin these electrodes can detect the tiny electrical changes on the skin due depolarizing and repolarizing of the heart muscles.

A 3-lead ECG provides basic information about the electrical activity of the heart, including the heart rate, rhythm, and any abnormalities in the electrical signals. The test can also detect some types of heart block, which occurs when the electrical signals that control the heart's rhythm are interrupted or delayed.

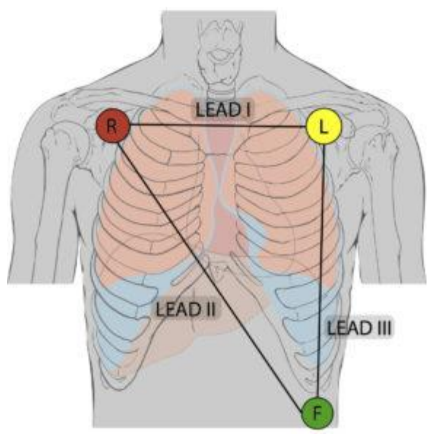


Fig. 2.9 : Electrode placement of 3 lead ECG electrodes

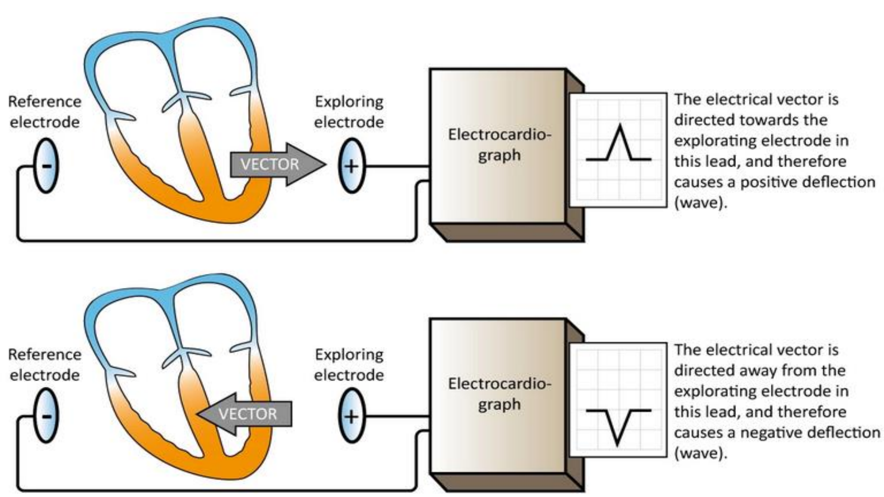


Fig. 2.10 : Comparing electrical potential difference generated by ECG lead.

The electrocardiograph defines one electrode as exploring (positive) and one electrode as reference (negative). Regardless of how the positive electrode and the negative are set up, the vector has the same impact on the ECG curve. A vector heading towards the exploring electrode yields a positive wave and a reference electrode as negative.[17]

Simulation:

12 Lead data input:

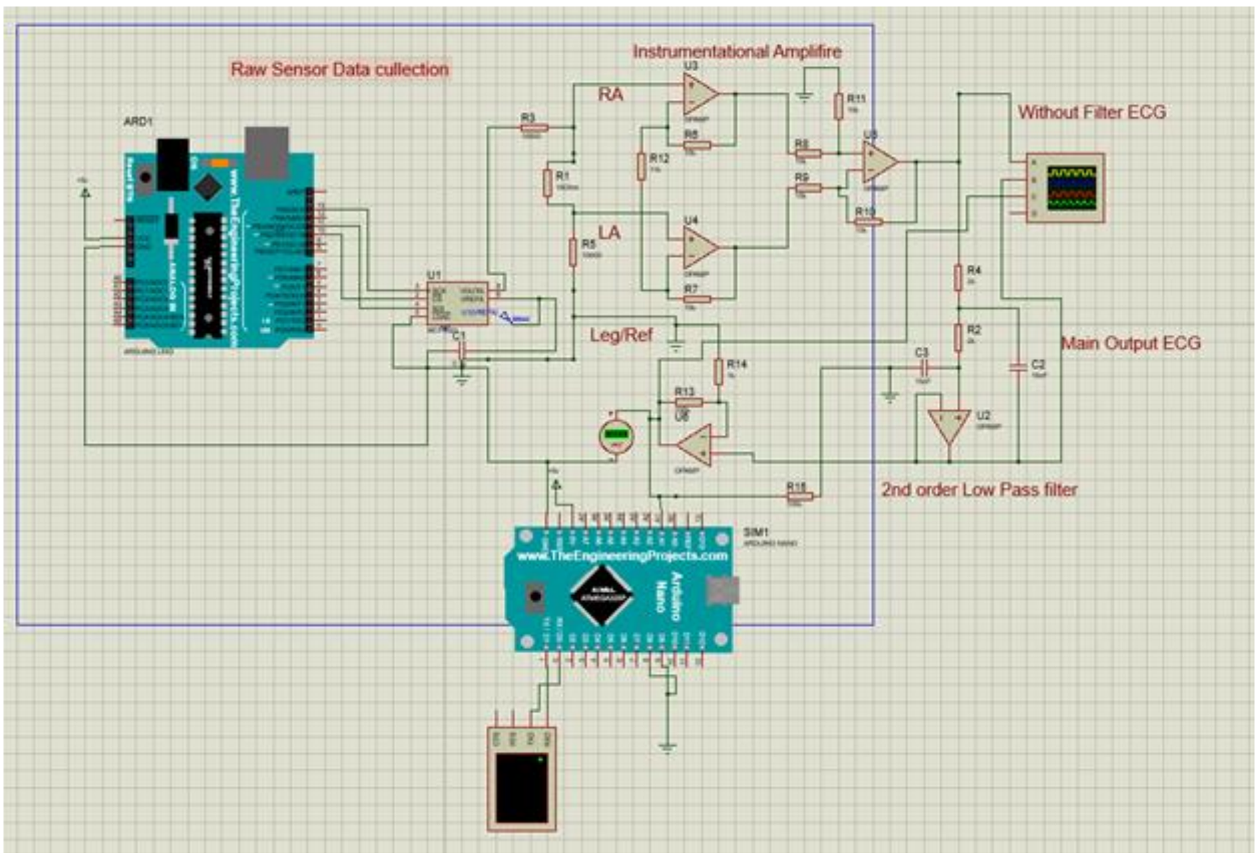


Fig. 2.11 : 3-lead circuit diagram for (12 lead data input)

Here in the circuit we have given 12 lead data which is collected from 12 different angel of human body. Here the Arduino UNO is working like human body. 12 lead actual ECG digital data have been given in Arduino code as input.

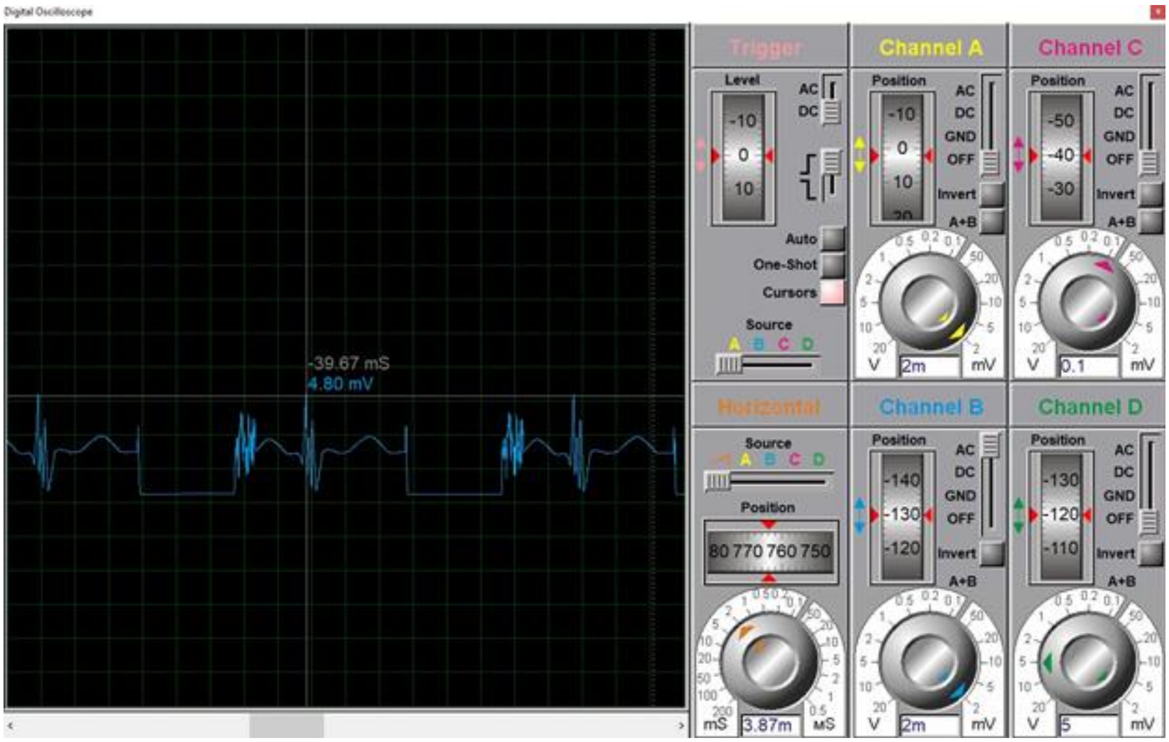


Fig.2.12 : 3 lead filtered graph

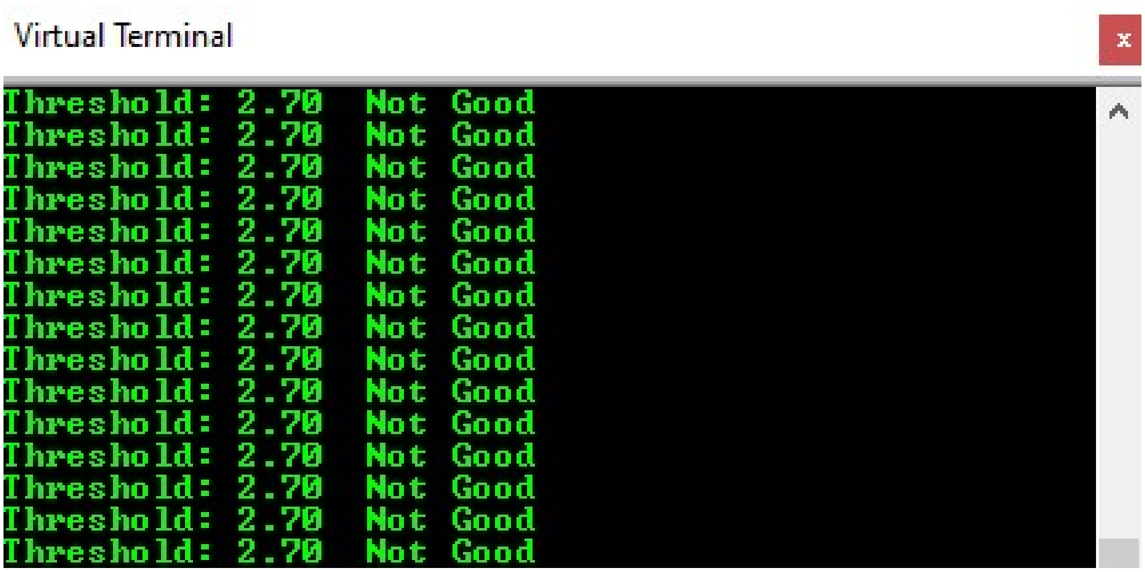


Fig.2.13 : Threshold voltage = 2.70mV for 3 lead.

Here, the threshold voltage is out of the range from 0.4mV to 1mV. Here the threshold voltage is 2.7mV so it is showing not good signal.

<u>3 Lead data input:</u>

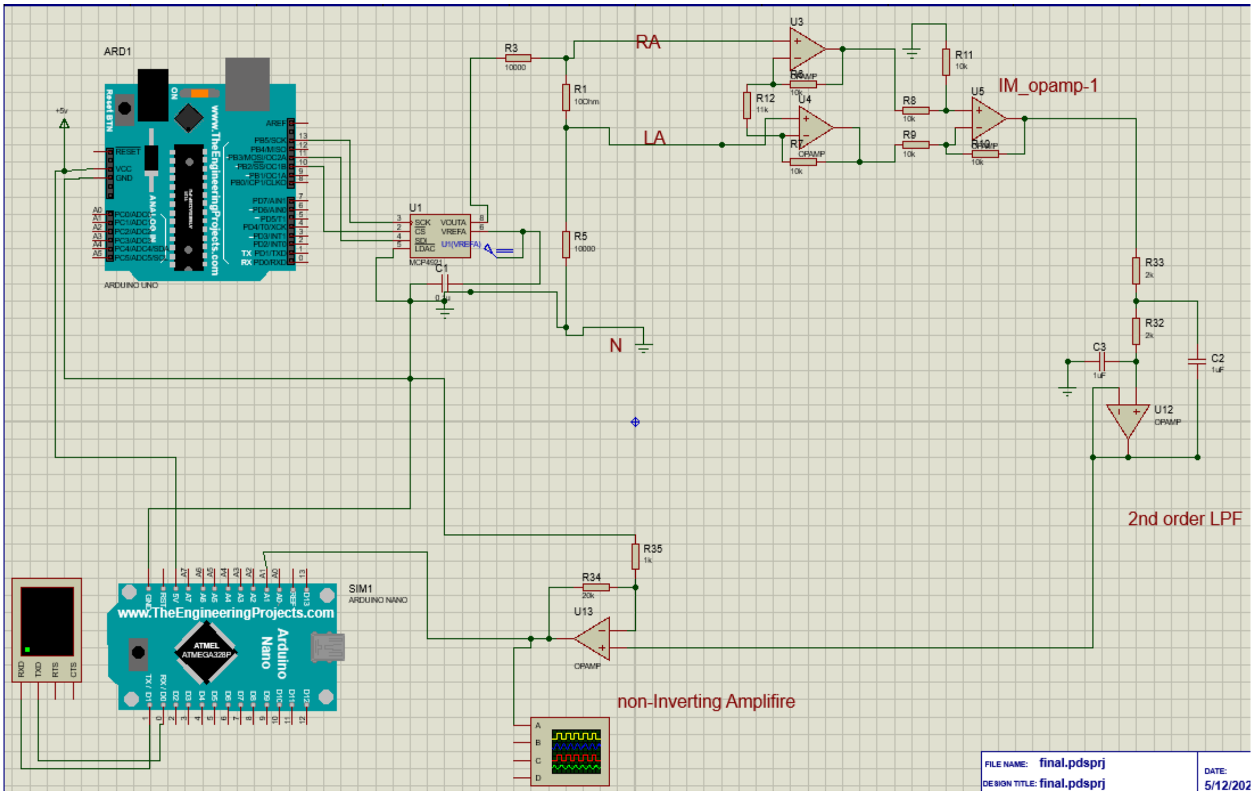


Fig.2.14 : 3 lead circuit diagram for (3 lead data input)

Here in the circuit by switching off lead 5 and lead 7 we make it 3 lead circuits. The input raw ECG data was for 3 lead which is coming from the arduino. Between each lead, we put a resistance which is compared to the human body. For 3 lead resistance are R1 & R2. The instrumentation amplifier is used in this circuit to extract the ECG signal by eliminating the noise. The first instrumentation amplifier is used for 3 leads.

3 lead calculation, ECG graph and threshold are given below.

Calculation:

Instrumentation amplifier:

$$\text{Gain, } A_v = 1 + \frac{2R_2}{R_{Gain}}$$

$$= 1 + \frac{2\times 10{,}000}{11{,}000}$$

$$= 2.8$$

There is only one instrumentation amplifier for 3 lead circuit. So, there is no need for a summing amplifier. That is why we do not need to calculate gain for calculate the gain for summing amplifier.

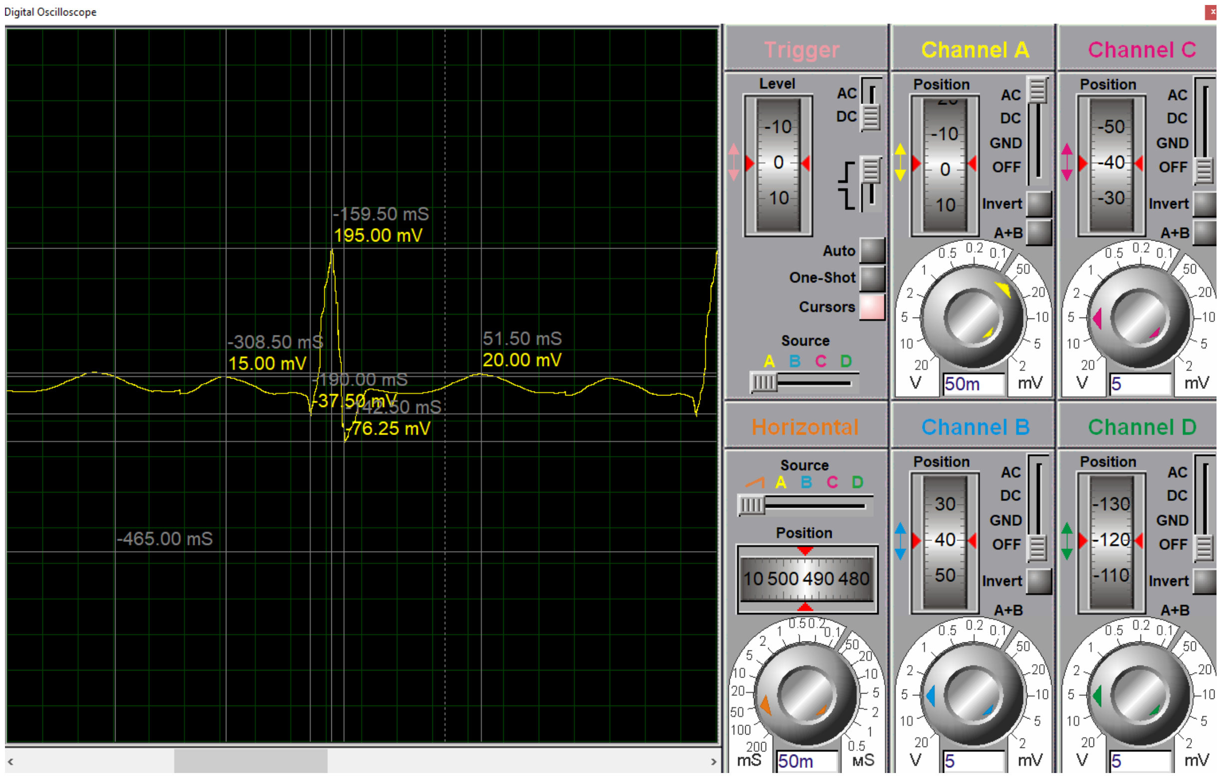


Fig.2.15 : 3 lead filtered graph

Fig.2.16 : Threshold voltage = 0.7mV for 3 lead.

Here, the threshold voltage is in the range from 0.4mV to 1mV. Here the threshold voltage is 0.7mV so it is showing good signal.

5-Lead Portable Heart Monitoring System:

An article about 5-Lead ECG Interpretation (Electrocardiogram) Tips for Nurses published in the FRESHRN website by K. Kleber on 11 November, 2022. In his article he wrote about 5 lead ECG and its placement. From the article we were able to learn that an ECG with 5 lead configuration requires a total of 5 electrodes placed onto the different parts of the human body. The placement of the 5 lead electrodes are given below:

- White is on the right side, just below the clavicle (midway).
- Black is on the left side just below the clavicle.
- Brown is in the 4th intercoastal space, just to the right of the sternum.
- Green is on the right on the lower edge of the rib cage.
- Red is on the left of the lower edge of the rib cage.

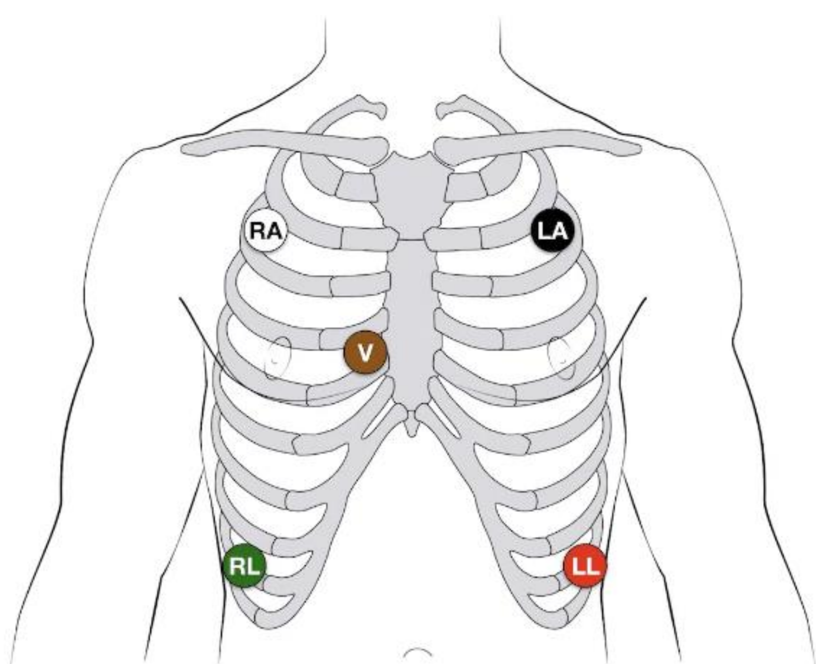


Fig.2.17 : 5 lead electrode placements

Five electrode systems can pick up rhythm abnormalities and ST segment deviations fairly well. This system is more often used in two channel monitors in which one limb lead and one chest lead are displayed simultaneously [18].

<u>Simulation:</u>

<u>For 12 lead data input:</u>

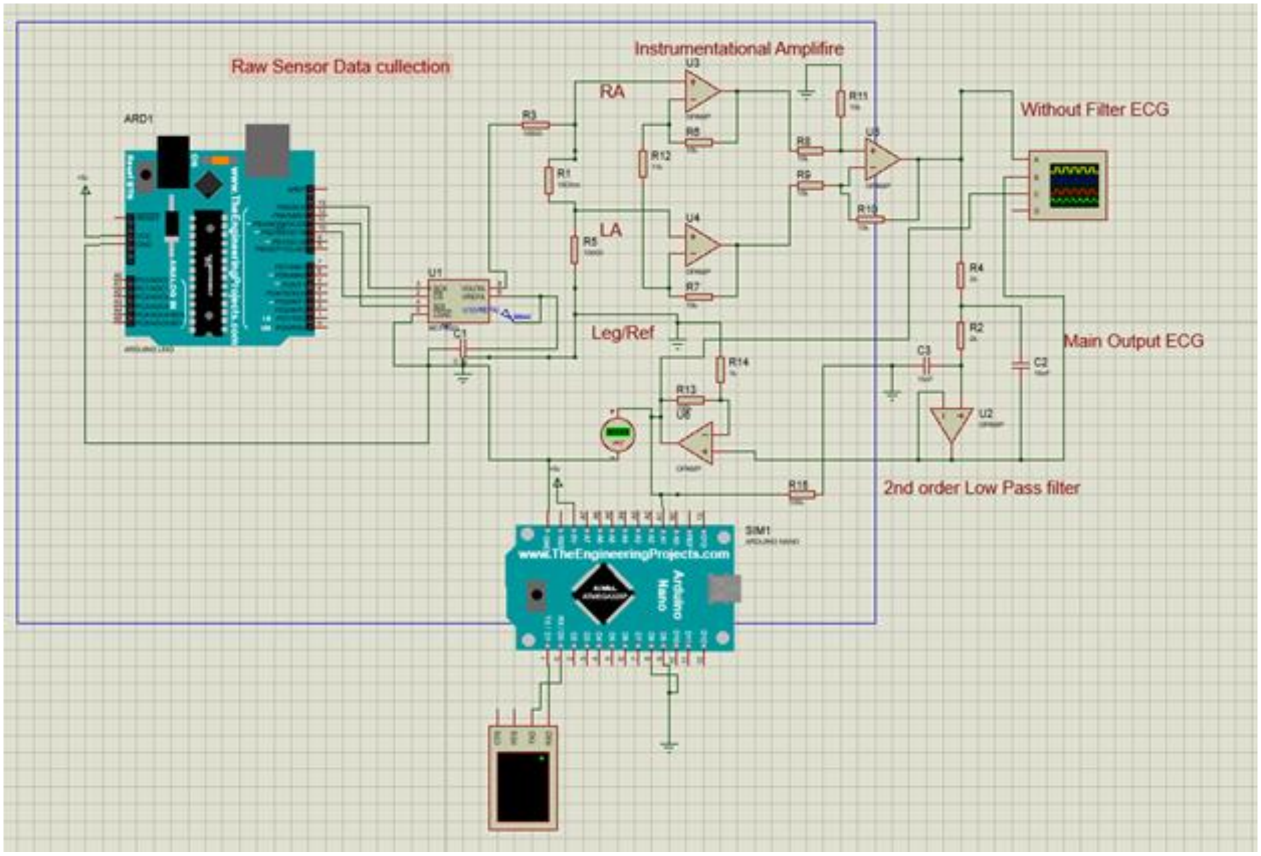


Fig.2.18 : 5 lead circuit diagram for (12 lead data input)

Here in the circuit we have given 12 lead data which is collected from 12 different angel of human body. Here the Arduino uno is working like human body. 12 lead actual ECG digital data have been given in Arduino code as input.

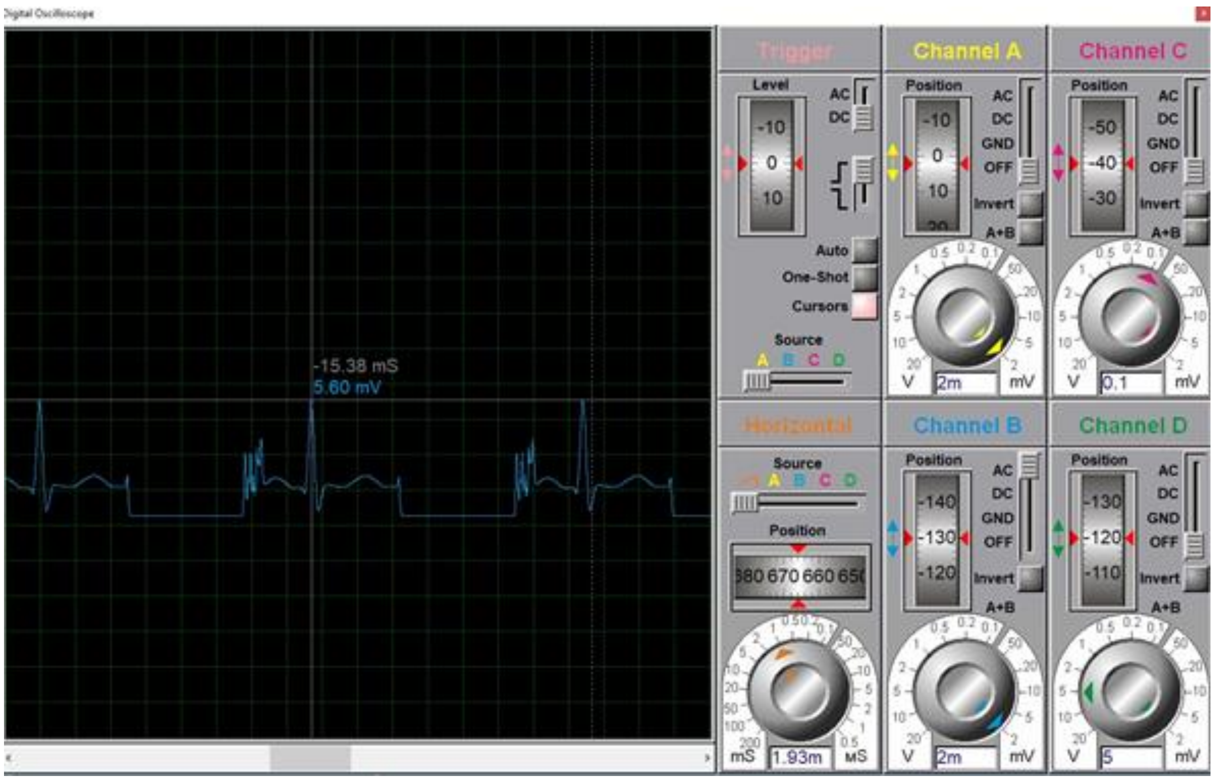


Fig.2.19 : 5 lead filtered graph

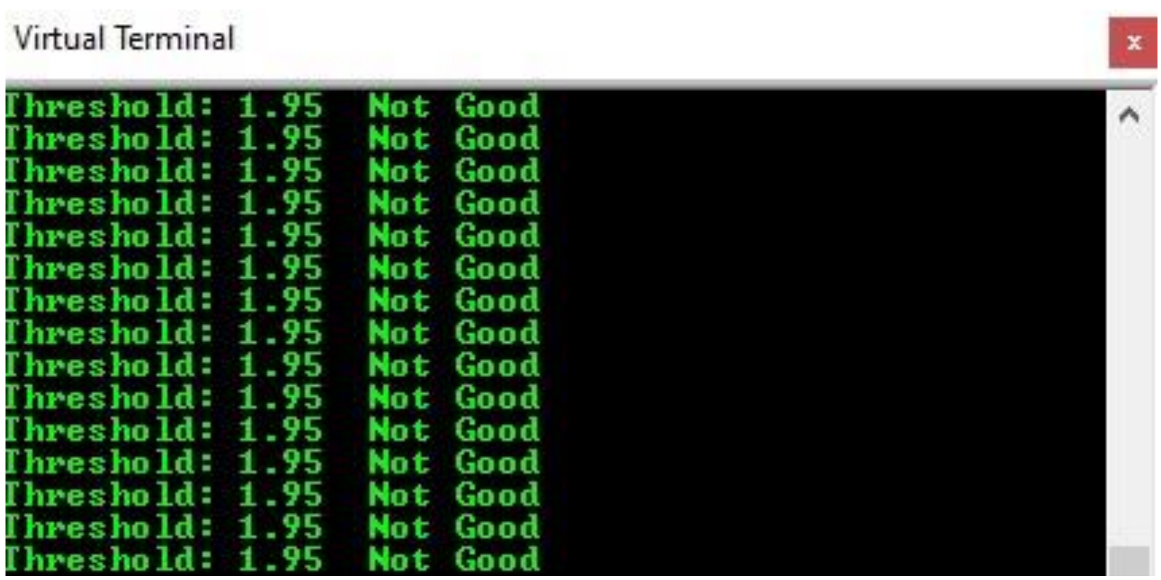


Fig.2.20 : Threshold voltage= 1.95mV for 5 lead

Here, the threshold voltage is not in the range from 0.4mV to 1mV. Here the threshold voltage is 1.95mV so it is showing not good signal.

<u>For 3 lead data input:</u>

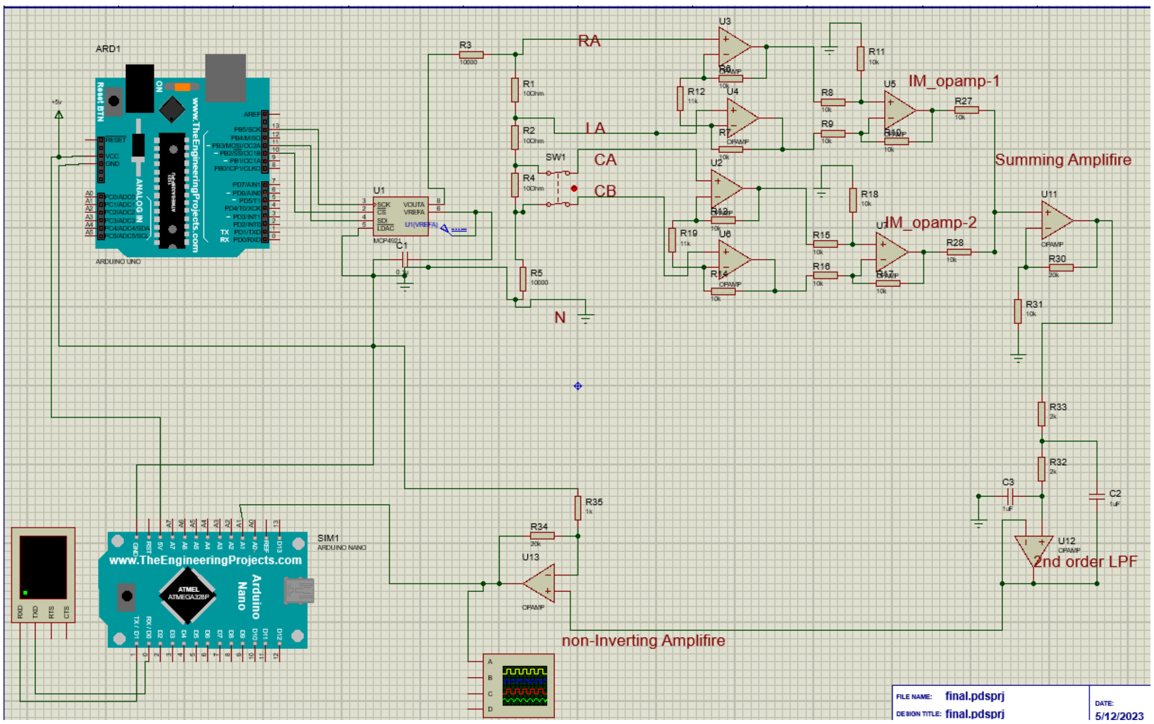


Fig.2.21 : 5 lead circuit diagram

Here in the circuit by switching off lead 7 we make it 5 lead circuits. The input raw ECG data was for 3 lead which is coming from the arduino. Between each lead, we put a resistance which is compared to the human body. For 5 lead resistance are R1, R2, R4. The instrumentation amplifier is used in this circuit to extract the ECG signal by eliminating the noise. The first two instrumentation amplifiers are used for 5 lead.
5 lead calculation, ECG graph and threshold are given below.
Instrumentation amplifier:

$$\text{Gain, } A_v = 1 + \frac{2R_2}{R_{Gain}}$$

$$= 1 + \frac{2\times 10{,}000}{11{,}000}$$

$$= 2.8$$

Summing amplifier:

$$\text{Gain, } A_v = 1 + \frac{R_a}{R_b}$$

$$= 1 + \frac{20{,}000}{10{,}000}$$

$$= 3$$

∴ Total gain = 2.8 × 3 = 8.4

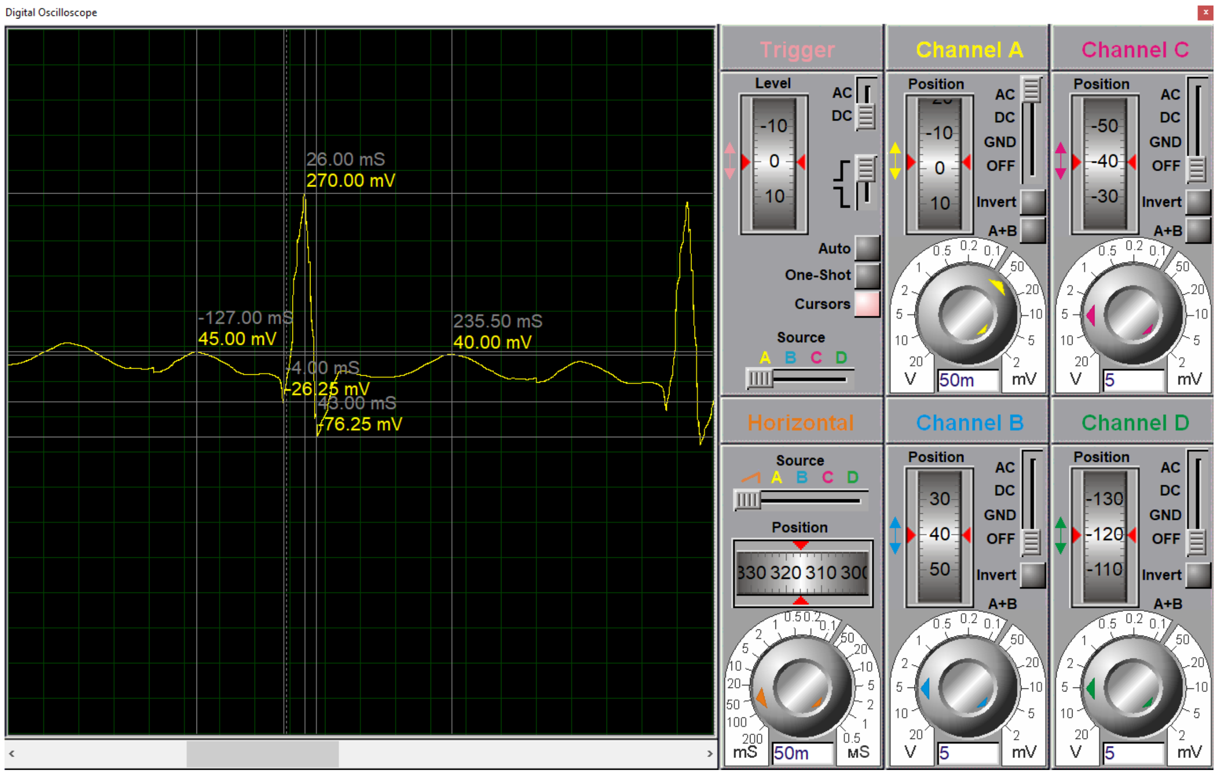


Fig.2.22 : 5 lead filtered graph

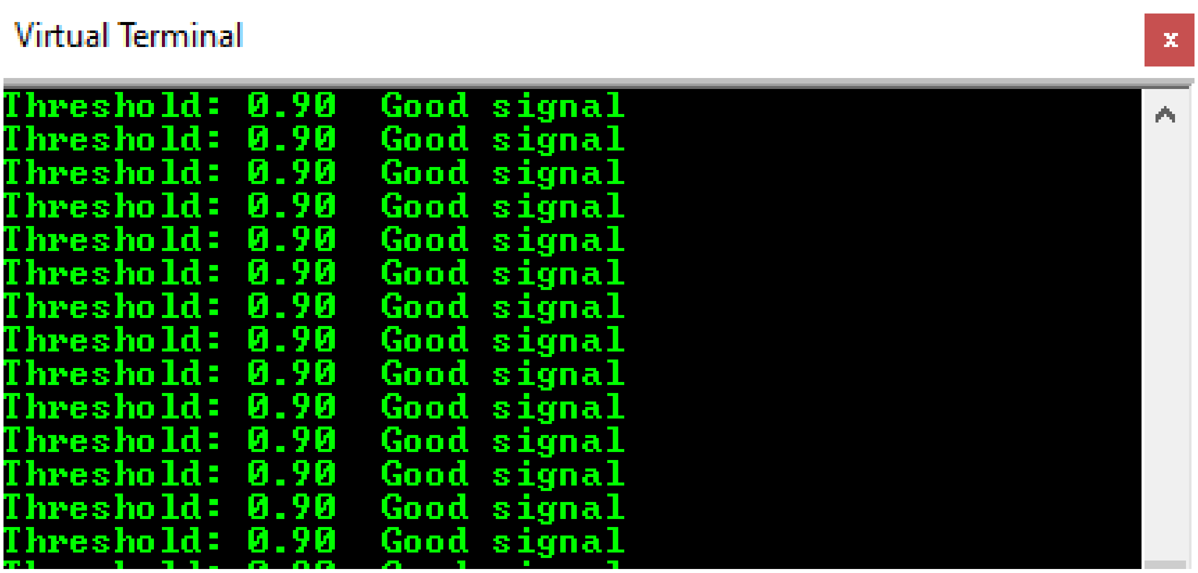


Fig.2.23 : Threshold voltage= 0.9V for 5 lead

Here, the threshold voltage is in the range from 0.4mV to 1mV. Here the threshold voltage is 0.9mV so it is showing good signal.

7-Lead Portable Heart Monitoring System:

7-Lead ECG means measure the electrical activity of the heart from seven different points on the body. It is obtained by placing four limb electrodes and three precordial electrodes on the patient's chest.

The four limb electrodes are placed on -

- the right arm,
- the left arm,
- the right leg and
- The left leg.

And the precordial electrodes are placed on -

- the right side of the chest,
- the left side of the chest, and
- the centre of the chest.

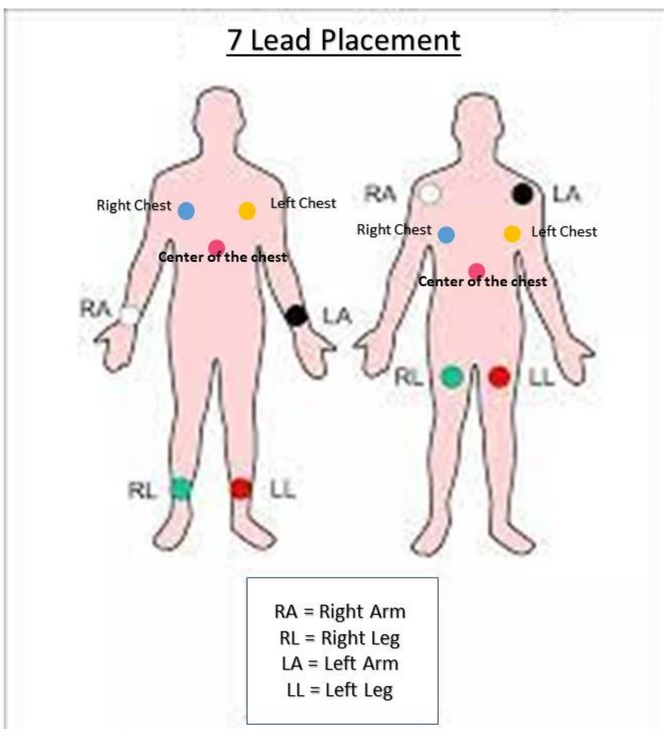


Fig.2.24: 7 lead electrode placements

The 7-lead ECG is often used when a more detailed assessment of the heart's electrical activity is needed, such as in patients with suspected arrhythmias or heart disease.

Simulation:

For 12 lead data input:

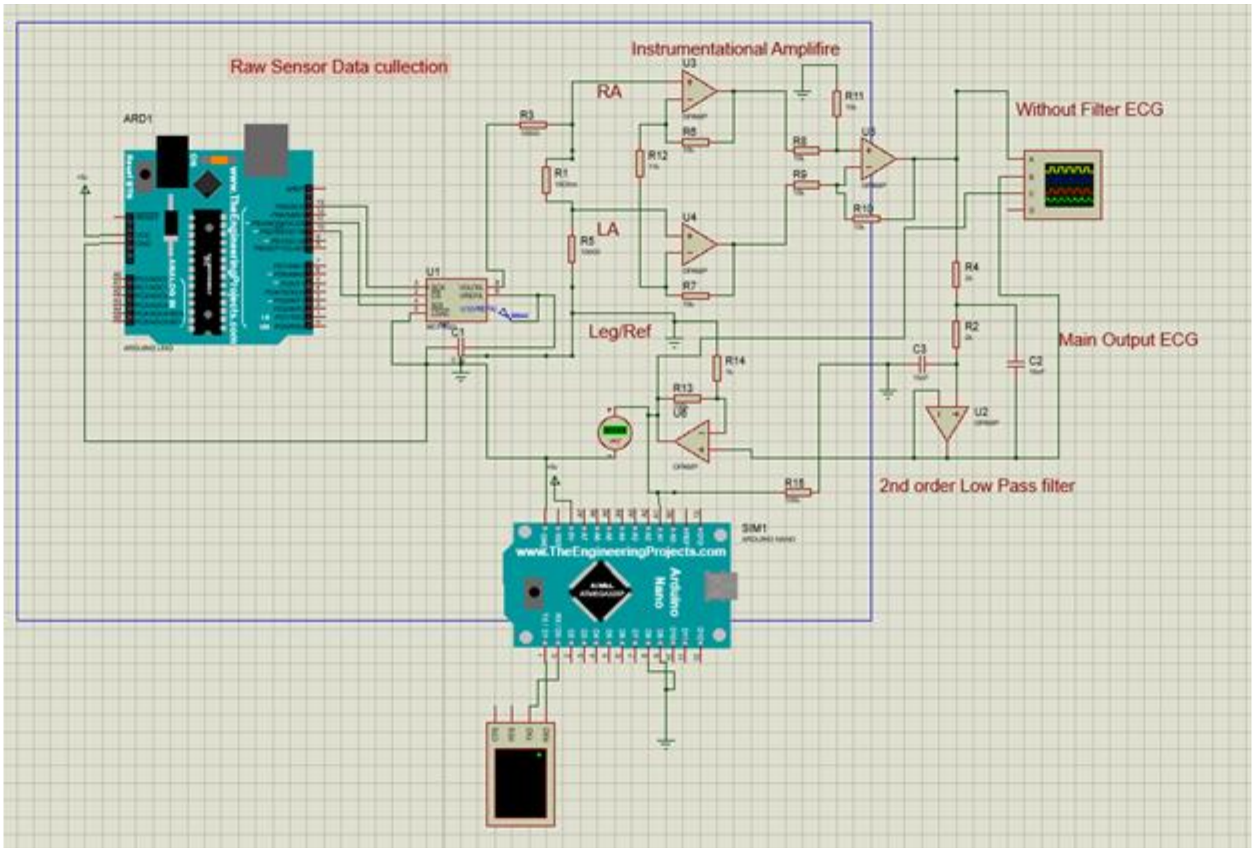


Fig.2.25 : 7 lead circuit diagram for (12 lead data input).

Here in the circuit we have given 12 lead data which is collected from 12 different angels of human body. Here the Arduino uno is working like human body. 12 lead actual ECG digital data have been given in Arduino code as input.

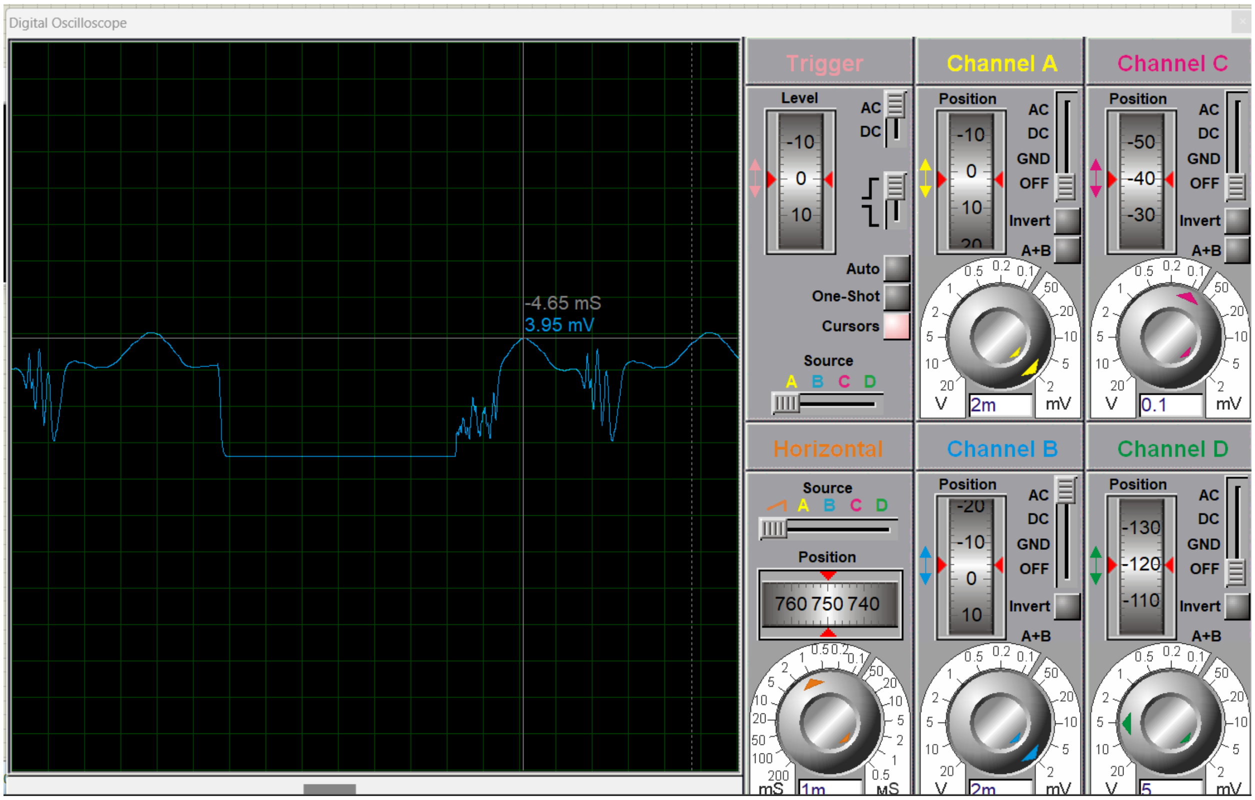


Fig.2.26 : 7 lead filtered graph

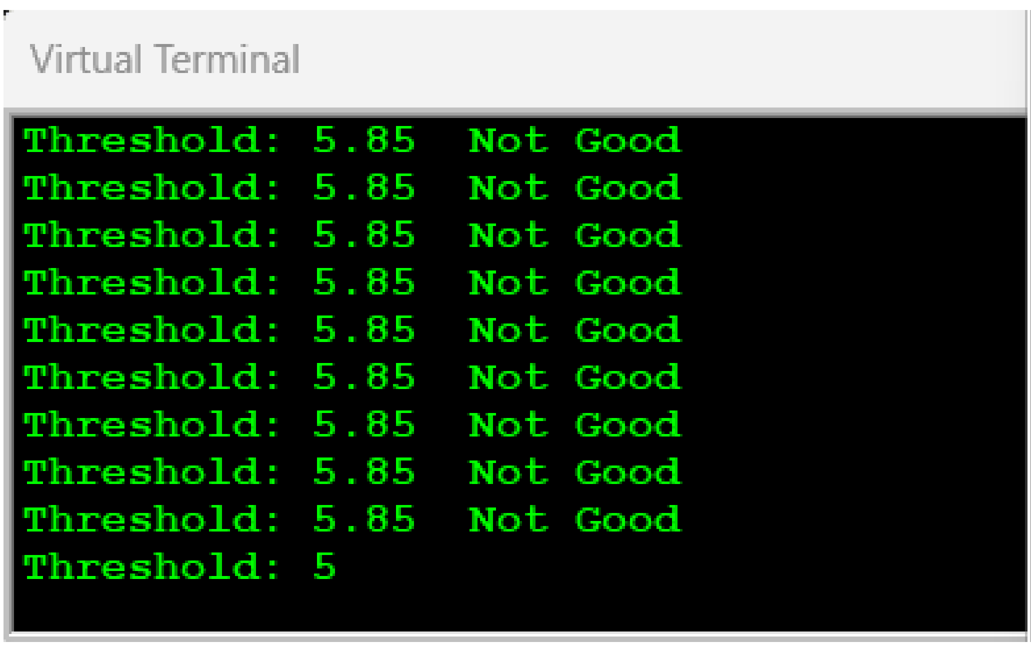


Fig.2.27 : Threshold voltage = 5.85mV for 7 lead.

Here, the threshold voltage is not in the range from 0.4mV to 1mV. Here the threshold voltage is 5.85mV so it is showing good signal.

<u>For 3 lead data input:</u>

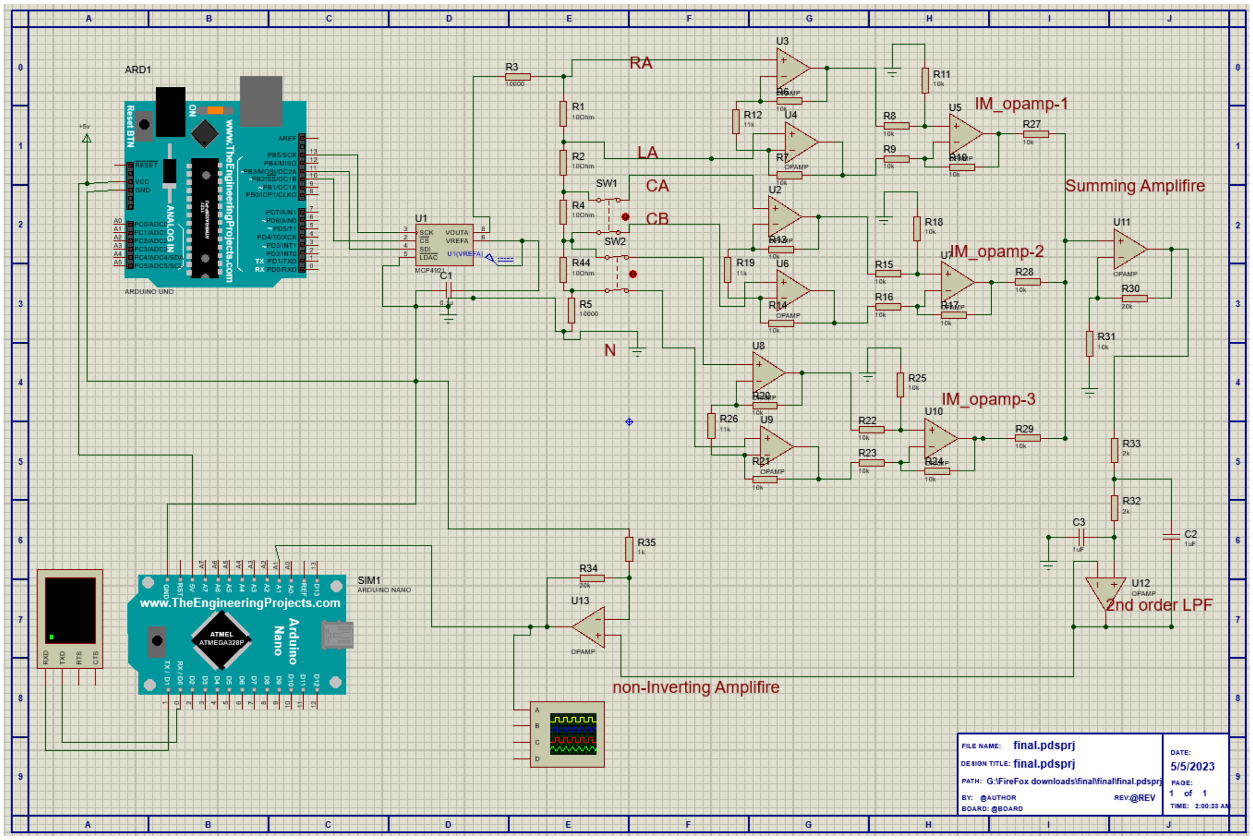


Fig.2.28 : 7 lead circuit diagram

Here in the circuit by switching on all the leads we make it a 7 lead ECG circuit. The input raw ECG data[22] was for 3 lead which is coming from the Arduino. Between each lead, we put a resistance which is compared to the human body. For 7 lead resistance are R1, R2, R4, R44, R5. The instrumentation amplifier is used in this circuit to extract the ECG signal by eliminating the noise.

7 lead calculation, ECG graph and threshold are given below.

<u>Calculation:</u>

Instrumentation amplifier:

$$\text{Gain, } A_v = 1 + \frac{2R_2}{R_{Gain}}$$

$$= 1 + \frac{2 \times 10{,}000}{11{,}000}$$

$$= 2.8$$

Summing amplifier:

$$\text{Gain, } A_v = 1 + \frac{R_a}{R_b}$$

$$= 1 + \frac{20{,}000}{10{,}000}$$

$$= 3$$

∴ Total gain = 2.8 × 3 = 8.4

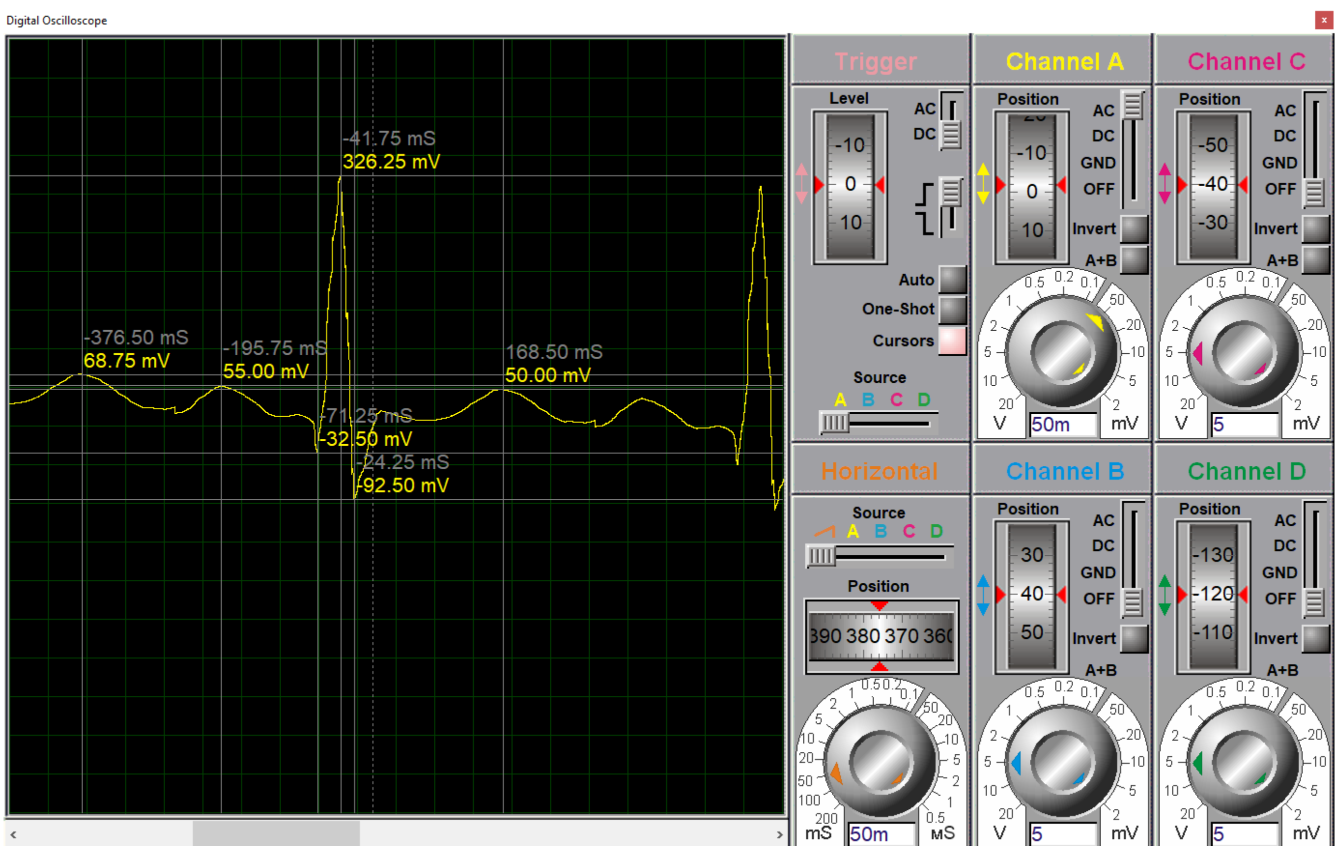


Fig.2.29 : 7 lead filtered graph

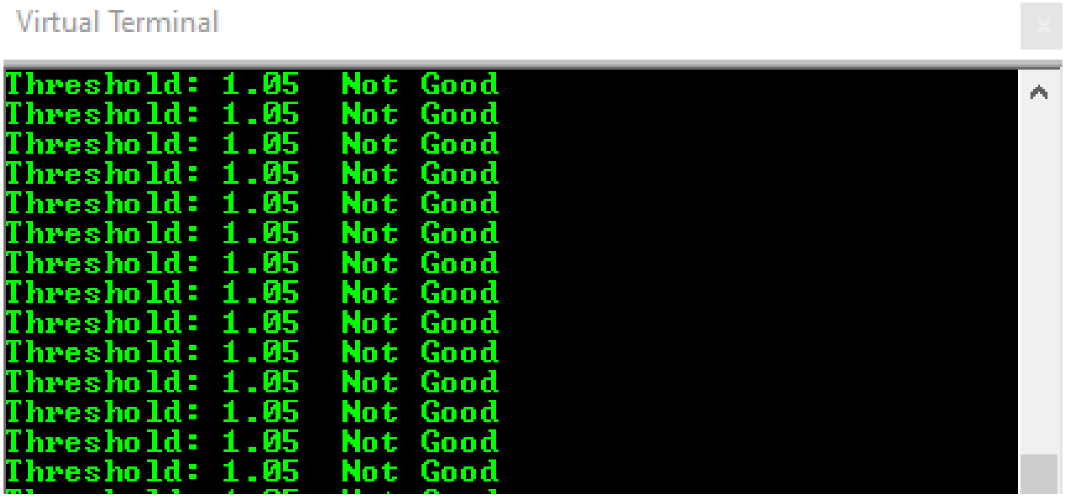


Fig.2.30 : Threshold voltage = 1.05mV for 7 lead

Here, the threshold voltage is not in the range from 0.4mV to 1mV. Here the threshold voltage is 1.05mV so it is showing good signal.

12-Lead Portable Heart Monitoring System:

A basic ECG is measured using electrodes. These electrodes are attached to the so-called 12-lead ECG device, which records the heartbeat at 12 separate body surface locations. Depending on the direction and amplitude of the electrical depolarization as it travels throughout the heart, the resulting ECG shows a mesh of cardiac electrical activity from the atrium and ventricles. The 12 ECG leads each reflect a unique 3-D direction of heart action [19].

The orientation of the 12 lead ECG is given below:

1. There are 3 leads which are called Bipolar Limb Leads:

    - Lead I: RA (-) to LA (+) (Right Left, or lateral)
    - Lead II: RA (-) to LL (+) (Superior Inferior)
    - Lead III: LA (-) to LL (+) (Superior Inferior)

2. There are another 3 leads which are called Augmented unipolar limb leads:

    - Lead aVR: RA (+) to [LA & LL] (-) (Rightward)
    - Lead aVL: LA (+) to [RA & LL] (-) (Leftward)
    - Lead aVF: LL (+) to [RA & LA] (-) (Inferior)

3. Other 2 leads are called Unipolar (+) chest leads:
    - Leads V1, V2, V3: (Posterior Anterior)
    - Leads V4, V5, V6:(Right Left, or lateral)

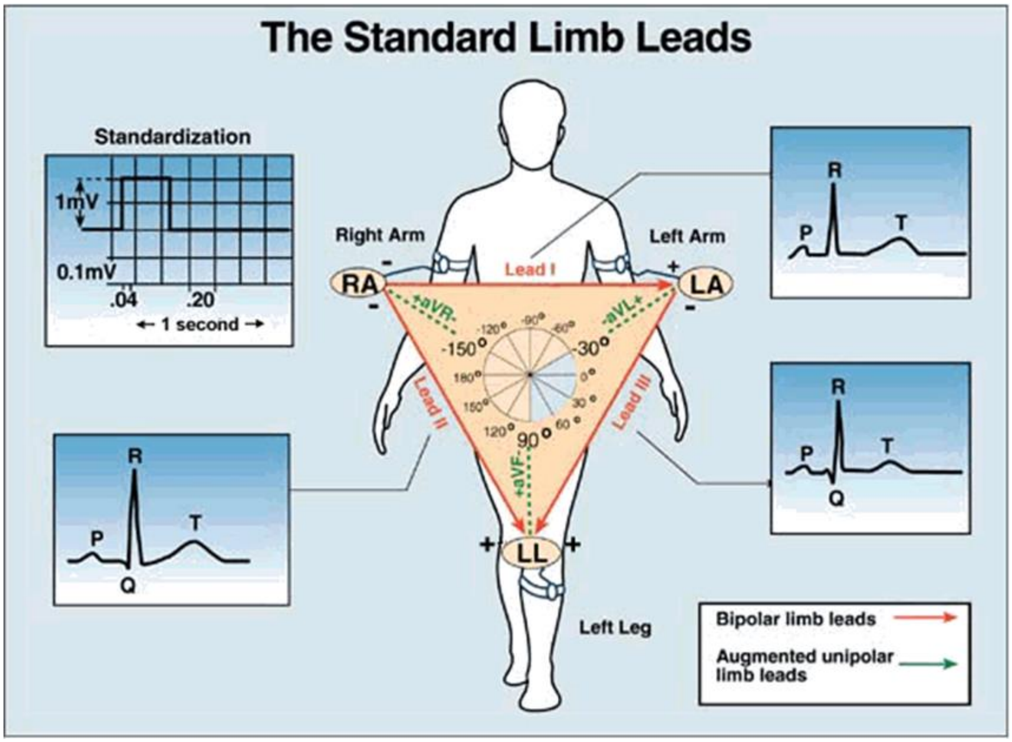


Fig.2.31 : Standard Limb Leads

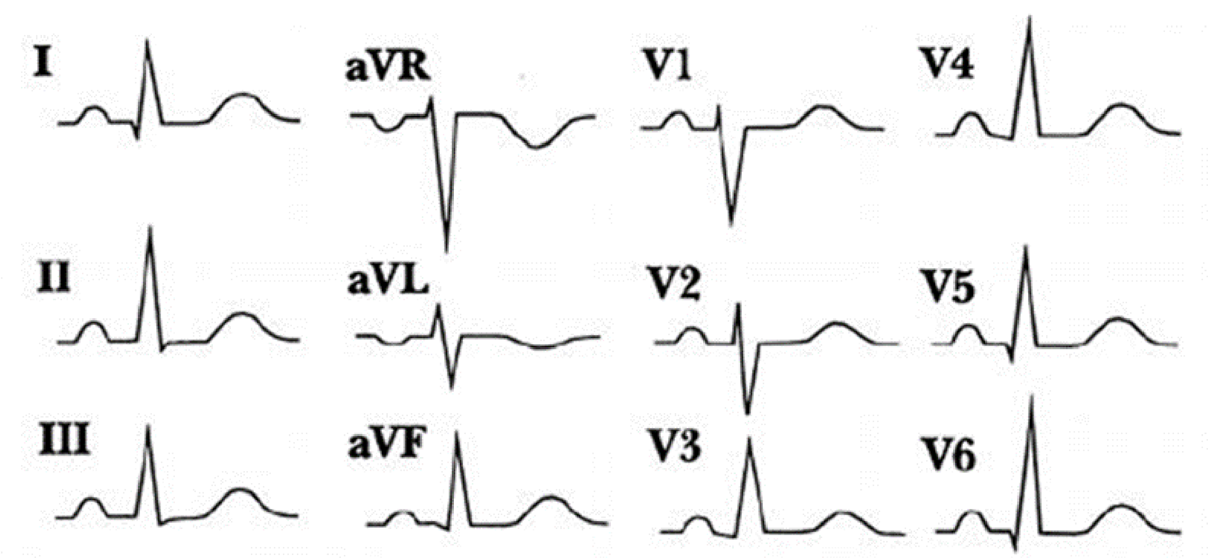


Fig. 2.32 : Basic appearance of the standard 12 lead ECG

There are some basic waves and intervals by which a physician can determine the exact problem of the heart. Some of the basic waves and intervals are given below:

Ø P wave: The simultaneous depolarization and activity of the right and left atria

Ø QRS complex: Depolarization of the right and left ventricles (normally the ventricles are activated simultaneously).

Ø QRS duration: The duration in which the ventricular muscle was depolarized.

Ø PR interval: The duration between the beginning of the P wave in the atrium and the beginning of the ventricular depolarization (QRS complex).

Ø QR interval: Ventricular depolarization and repolarization duration.

Ø PR interval: Ventricular cardiac cycle duration (an indicator of ventricular rate).

Ø PP interval: Atrial cycle duration (an indicator of atrial rate).

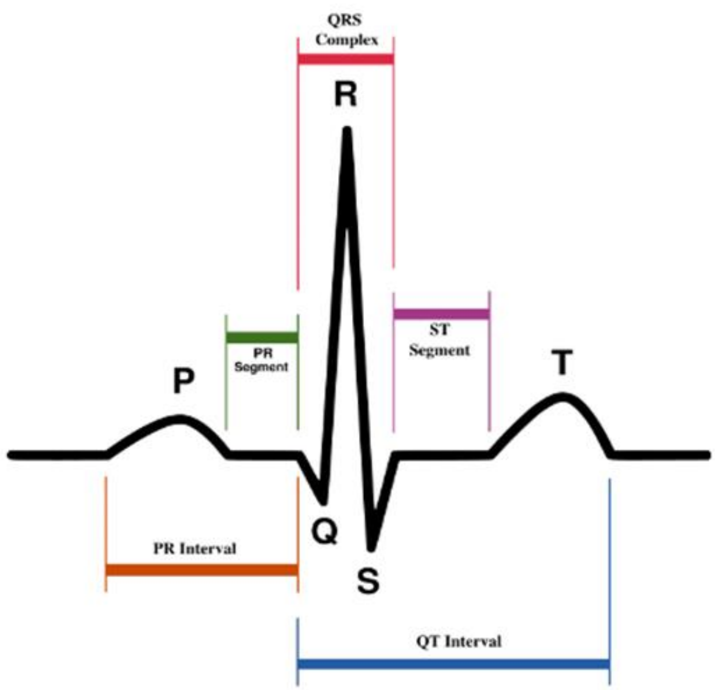


Fig.2.33: The parameters of an ECG recording during a single cardiac cycle (single heartbeat)

The electrodes have to be placed on the exact standard position every time to get an accurate result. Compared to an outpatient Holter or Event monitor, the 12-lead ECG provides better details on the diagnosis of one's heart arrhythmia [19].

Simulation:

For 12 lead data input:

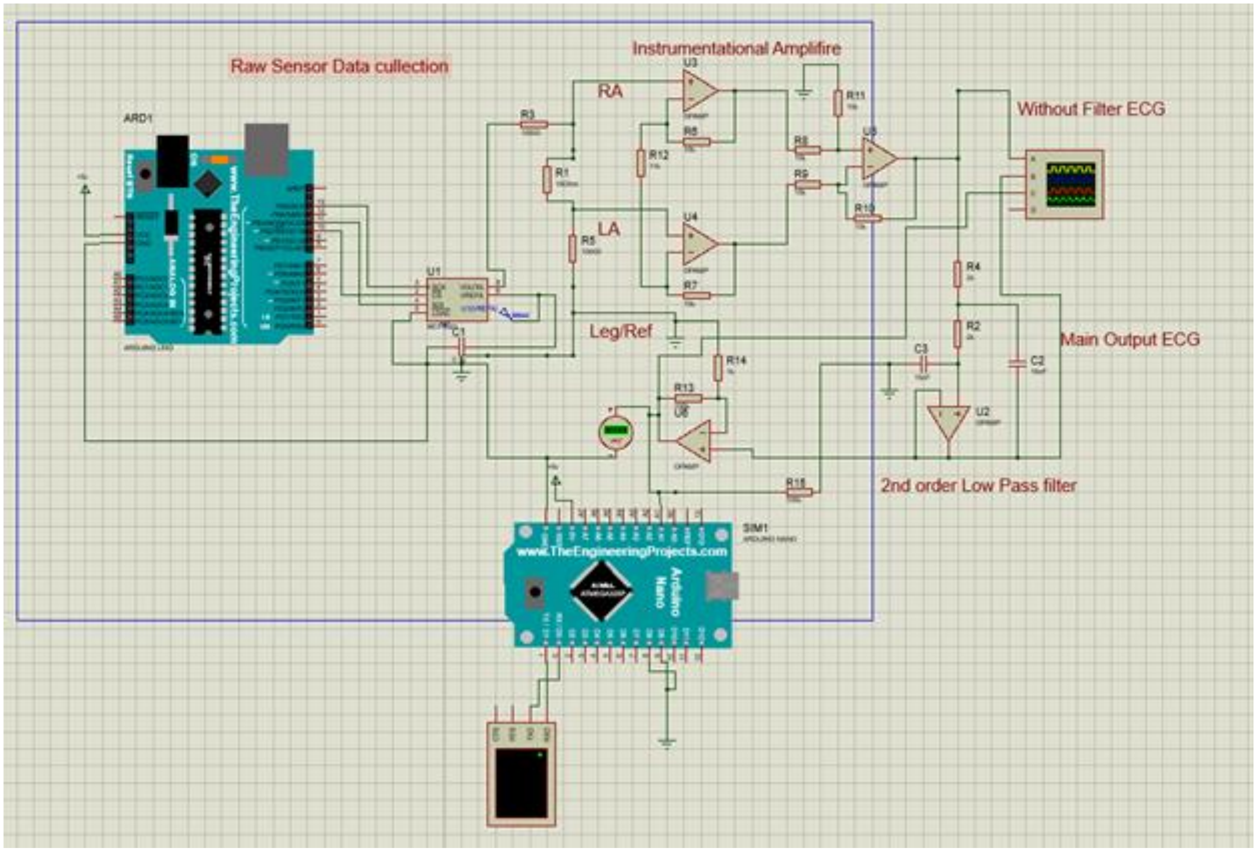


Fig.2.34 : 12 lead circuit diagram for (12 lead data input)

Here in the circuit we have given 12 lead data which is collected from 12 different angel of human body. Here the Arduino uno is working like human body. 12 lead actual ECG digital data have been given in Arduino code as input.

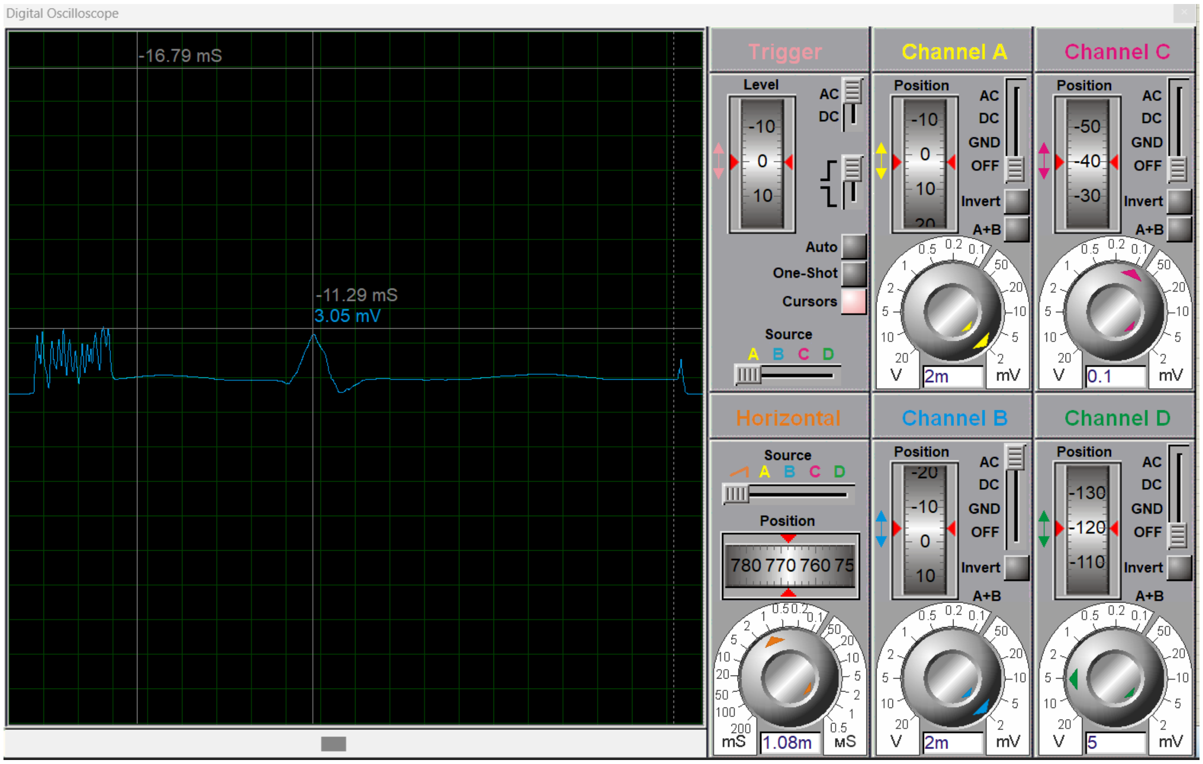


Fig.2.35 : 7 lead filtered graph

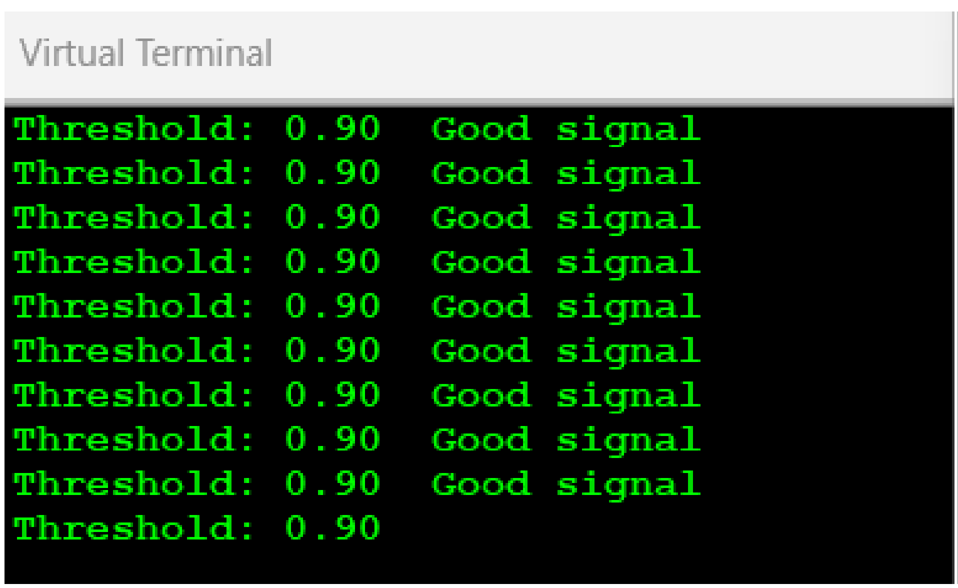


Fig.2.36 : Threshold voltage = 0.9mV for 12 lead.

Here, the threshold voltage is in the range from 0.4mV to 1mV. Here the threshold voltage is 0.9mV so it is showing good signal.

In this part our main target is to design and simulate our project proposal. In EEE400A we proposed a topic of portable heart monitoring electrocardiogram device. Here we are trying to simulate the system. At first, we designed a circuit in proteus. In that circuit we load a 12 lead ECG data which can convert the data into 3 lead, 5 lead and 7 lead. But for this design we only got a valid result for 12 lead system which is 0.90 mV (threshold voltage). But other than that, the rest of the values were over the 0.4-1 mV range. As our simulation is not complete and we did not get accurate results, so we modified the entire circuit differently. For the updated design we have differentiated the leads into 3 different types which were 3-lead, 5-lead and 7-lead and we did that by using various instrumentation amplifiers. We have designed 3 different circuits which represent the different lead systems. But this time instead of loading 12 lead data we loaded 3 lead data which we collected from the internet. After simulating the modified design, we can see that our results are much more accurate than the previous design. For this circuit we can see that for 3 lead and 5 lead we are getting the threshold voltage in the range which is 0.7mV and 0.9mV respectively. And our output graph is much more noise free and clear. But unfortunately for this particular design our 7-lead threshold voltage is 1.05mV which is slightly over the range. And also, we could not simulate the system for 12-lead as the circuit was getting very much complicated. And, we had some limitations during simulating the system on proteus.

Table 2.1: Comparison of Threshold Voltages for Different Lead:

Leads	**12-Lead Data Input**	**3-Lead Data Input**
3 - Lead	2.70mV (not good signal)	0.7mV (good signal)
5 - Lead	1.95mV (not good signal)	0.90 mV (good signal)
7 - Lead	5.85mV (not good signal)	1.07mV (not good signal)
12 - Lead	0.90mV (good signal)	Not found

According to reference paper “R–Peak Detection of ECG Signal using Thresholding Method” [20], we compared our ECG threshold voltage value from 0.4mV - 1m. As per this comparison, we decide our threshold value’s output quality whether the output signal is good or bad.

So, from the table 2.1: Comparison of Threshold Voltages for Different Lead, it provides information on the threshold values obtained from using different lead systems on different types of data, 12-lead and 3-lead data. The threshold values indicate the minimum voltage signal required for good signal quality, whereas a higher threshold value indicates a weaker signal.

Table-2.1, shows that using 12-lead data on a 3-lead system resulted in a threshold value of 2.70mV, which could be better. However, using 3-lead data on the same 3-lead system produced a threshold value of 0.7mV, which is a good signal.

Fewer leads can result in better signal quality for the specific data type.

Similarly, using 12-lead data on a 5-lead system produced a threshold value of 1.95mV, whereas using 3-lead data on the same 5-lead system resulted in a lower threshold value of 0.90mV. This shows that fewer leads can improve signal quality for both data types.

In contrast, using 12-lead data on a 7-lead system resulted in a threshold value of 5.85mV, which could be better. Using 3-lead data on the same 7-lead system also produced a threshold value of 1.07mV, which is not good either. Adding more leads may only sometimes result in better signal quality.

Finally, using 12-lead data on a 12-lead system resulted in a threshold value of 0.90mV, which is a good signal. This is expected as the system is designed to work optimally with 12 leads.

This table-2.1 highlights the importance of considering the number of leads and the data type used when designing a lead system for acquiring signals.

Calculation of Portable Heart Monitoring System Circuit Diagram:

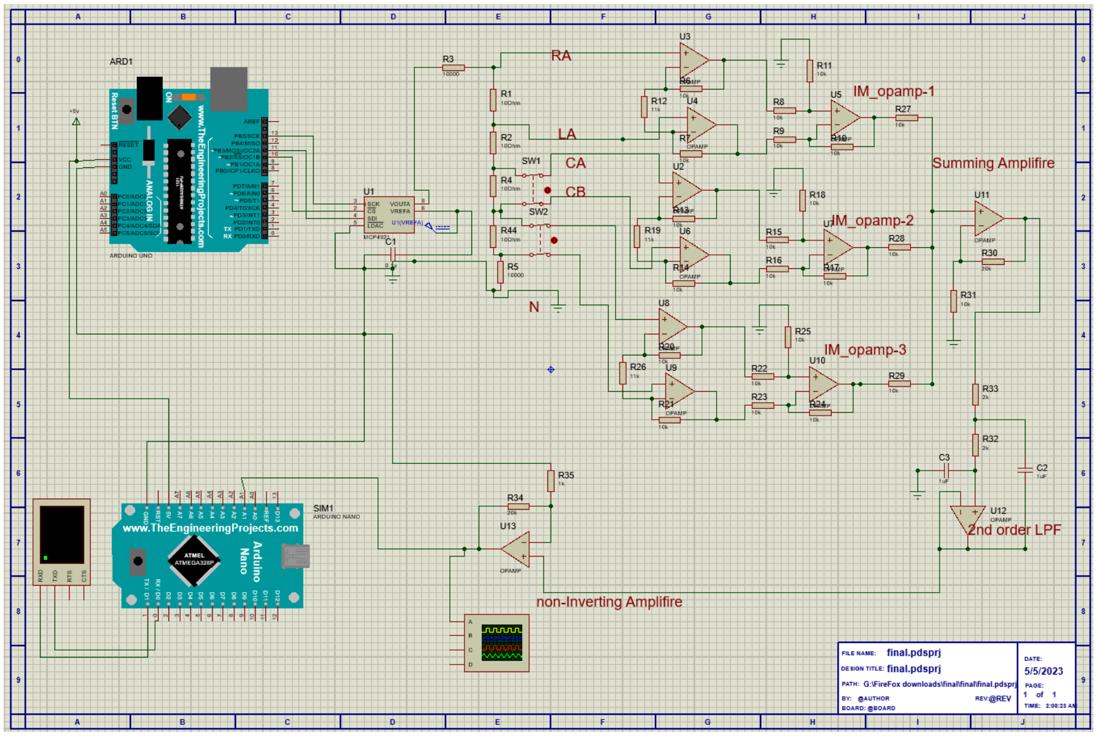


Fig.2.37 : Portable ECG Monitoring System Circuit Diagram

For cutoff frequency of second order low pass filter formula is given below,

$$fc = \frac{1}{2\pi\sqrt{R32\ R33\ C2\ C3}}$$

In our circuit,

R32 & R33 = 2K = 2000Ω

C2 & C3 = 1uF = 1×10^{-6}F

$$fc = \frac{1}{2\pi\sqrt{R32\ R33\ C2\ C3}} = 79.58 \text{ Hz} = 80 \text{ Hz (appx)}$$

When a low pass filter is used to remove high frequency noise from an ECG signal, it is possible to set the cutoff frequency to a low value. However, if the cutoff frequency is set too low, some of the high-frequency components of the actual ECG signal will also be removed along with the noise. This can make it challenging to process the signal accurately because some of the important information in the signal may have been lost. Therefore, it is important to select an appropriate cutoff frequency that will remove the unwanted noise while preserving the important features of the ECG signal.

For non-inverting amplifier:
$\frac{V_{out}}{V_{in}} = 1 + \frac{R_{34}}{R_{35}} = 101$

Heart Rate Calculation:

$$\text{Average Heart Rate (bpm)} = \frac{60}{\text{Average R−R Interval (In sec)}} \text{ [2].}$$

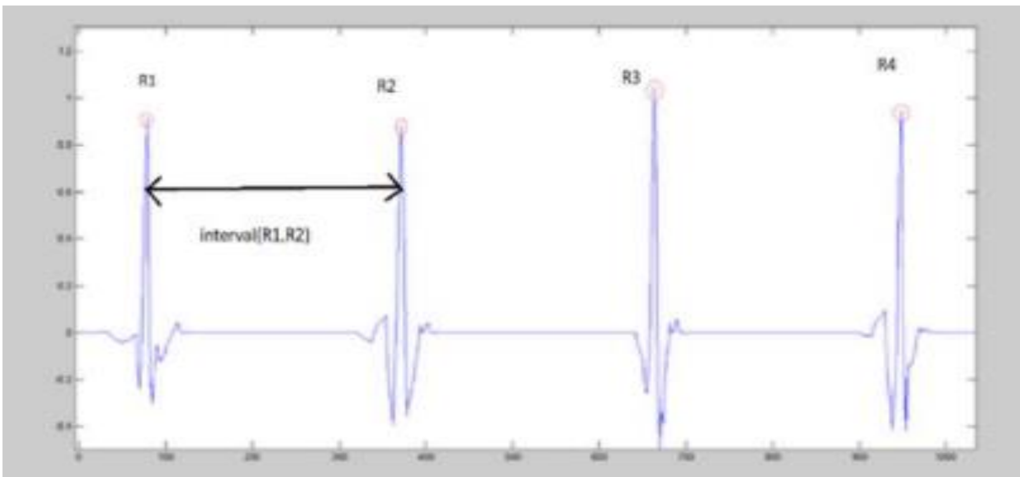


Fig.2.38 : Heart Beat Calculation

Portable Heart Monitoring Device using Microneedle Electrode Sensor:
Microneedle is an ECG electrode that uses tiny, needle-like sensors to pick up electrical signals from the body. Microneedle electrodes are typically made of a conductive material, such as silver, and are inserted into the skin to a depth of a few millimetres, to penetrate the skin and reach the underlying muscle tissue. A thin wire is attached to the needle that transmits the electrical signals generated by the heart to a monitoring device. The electrode sensor may consist of an array of needles that are arranged in a specific pattern to capture the electrical activity of the heart from different angles. The needles are typically very thin and short, so they do not cause much discomfort or pain [7].

Measurements of a microneedle electrode [7] should be,
Substrate = 4 mm × 4 mm silicon wafer
Microneedle length = 100 μm to 200 μm and
Diameters = 30 μm to 50 μm

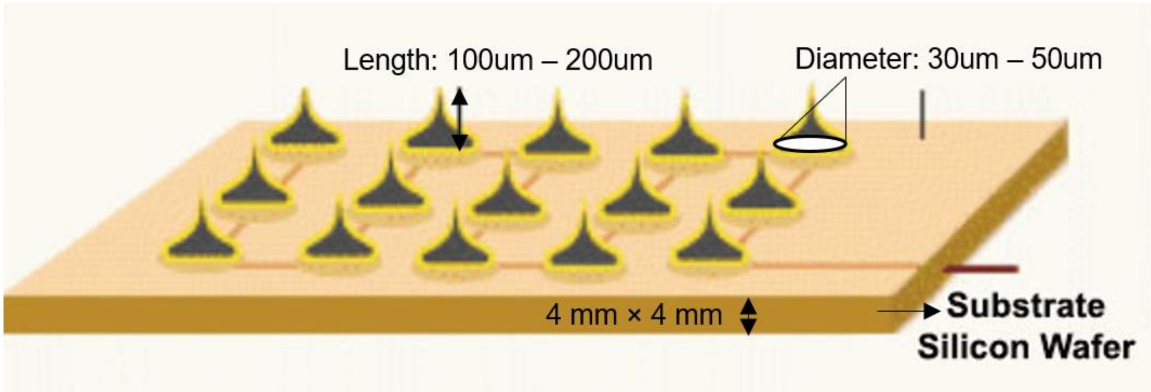


Fig.2.38 : Micro-needle electrode

UART WIFI Converter: UART-Wi-Fi converter is a device that can provide wireless connectivity to a device that has a UART interface. In the context of ECG, the converter can be used to transmit the ECG data wirelessly to a remote monitoring station. The converter typically includes a UART interface for connecting to the ECG device and a WiFi module for providing wireless connectivity. Here the main MCU will collect data from electrodes and then process data using AFE (Analog Front-End), SD card, USB and UART-WIFI Converter. Then show the output using a real-time display. After their system debugging and detection, the overall system design showed ideal, stable performance, the optimal state power consumption, they also mentioned that the ECG waveform and heart rate value can be dynamically displayed in the local LCD and Android client, and the ECG data is locally implemented SD card storage and internet remote transmission. Once the connection is established, the ECG data can be transmitted wirelessly to the monitoring station for analysis and monitoring that meets the requirements for wireless connectivity and data transfer [8].

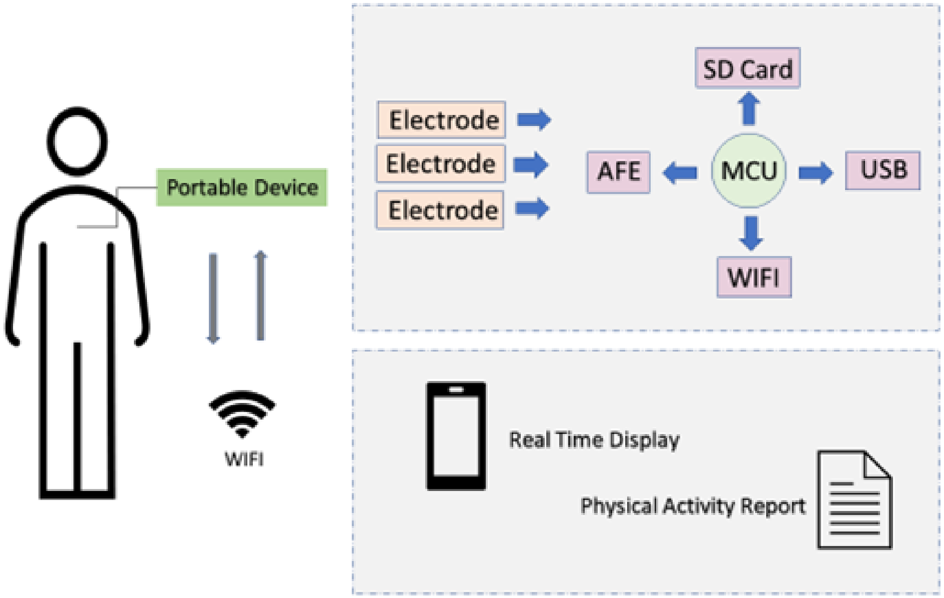


Fig.2.39 : Schematic diagram of using WIFI Converter

Bluetooth: The use of capacitive electrode interfacing between portable heart monitoring device and smartphone. The weak ECG signals extracted from the dry electrode can be amplified, band-pass filtered, analogue digital converted and so on. Finally, it will be sent to the mobile phone by Bluetooth technology for real-time display on screen. The core ECG monitoring circuit is composed of a CMOS preamplifier ASIC designed by the authors which can operate steadily, precisely and display the ECG in real-time [9].

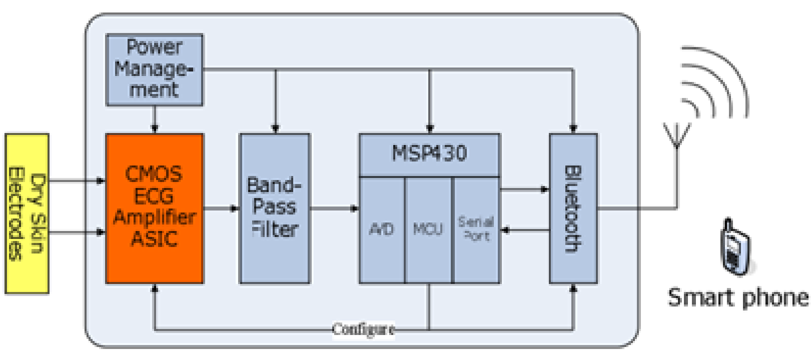


Fig.2.40 : Schematic diagram of using Bluetooth

So between **UART Wi-Fi** and **Bluetooth**, we will keep these both features because these two functionalities are very available in our daily life uses [9].

As per some limitations in proteus software we could not simulate our another alternate solution which was based on data accusation. In proteus software there were no library function by which we may simulate UART-WIFI Converter and Bluetooth. That is why we could not simulate these two alternate solution.

2.3 Refined design

Our main target in EEE400B was to virtually simulate the main idea. In the process of that we have simulated two different designs. At first, we designed a fundamental circuit which could convert a 12 lead data into different leads and give us the output. But from that design we were not getting the accurate result which we wanted. So, after that we completely modified the design.

<u>Refined Simulation for 7 -Lead:</u>

Our refined design simulation is based on Fig.4.6, where we change the resistance value 20kΩ to 16 kΩ.

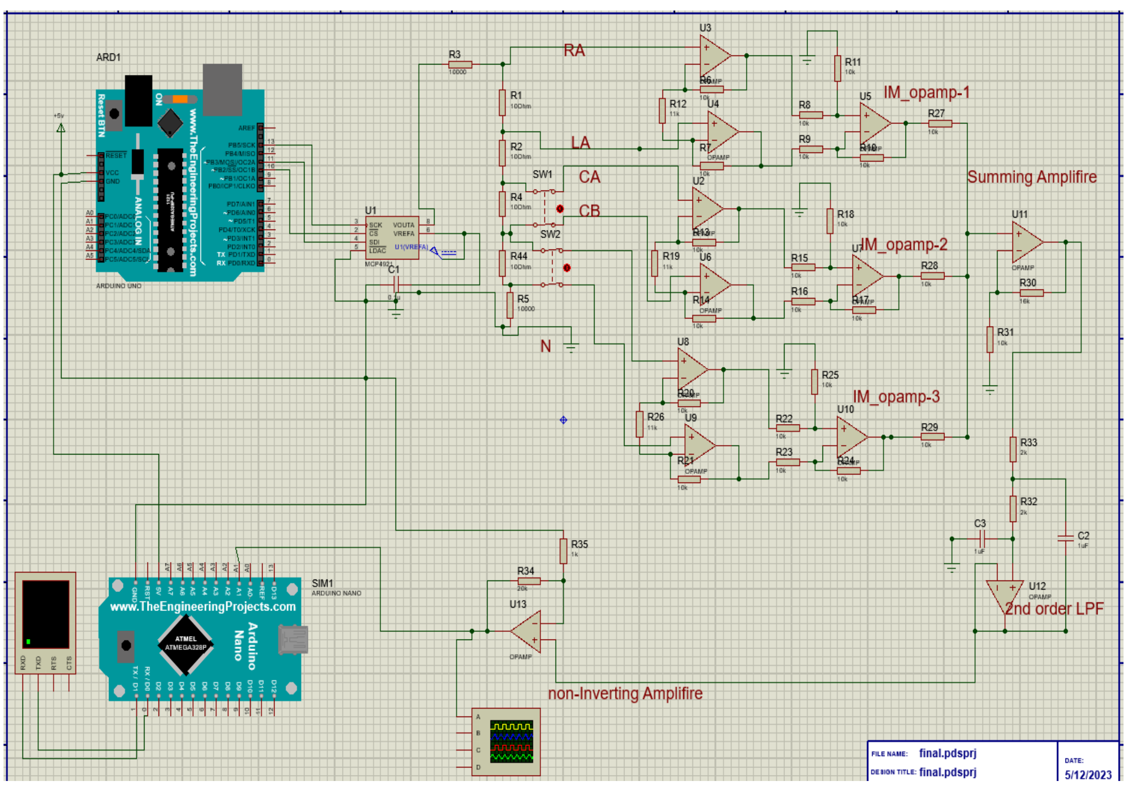


Fig.2.41 : Refined 7 lead Portable ECG Circuit

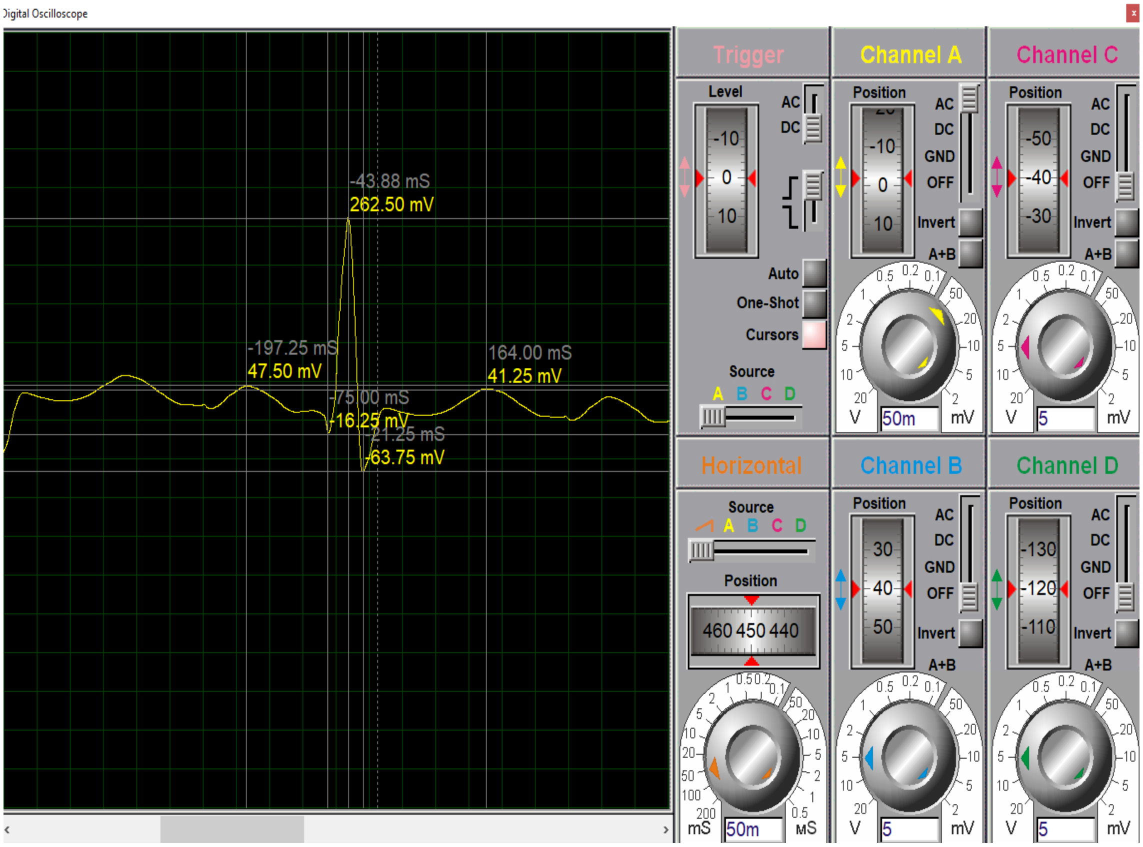


Fig.2.42: Refined 7-Lead Graph

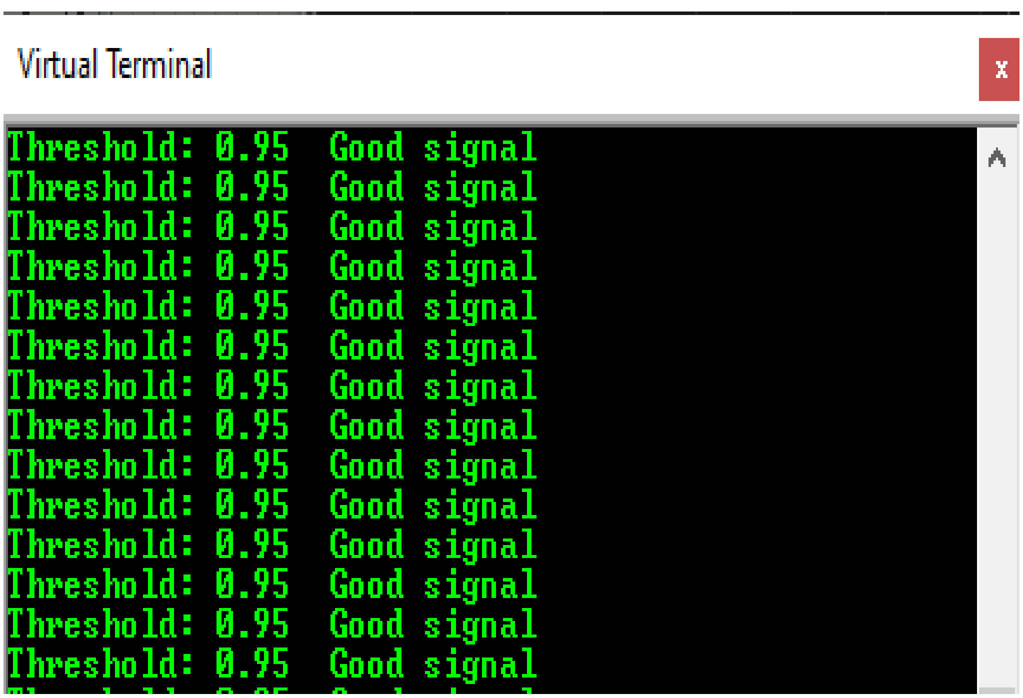


Fig.2.43: Refined 7-Lead Threshold Output

As we described before, in our simulation section we updated the design for 3-lead, 5-lead and 7-lead. But we only got satisfactory result for 3 and 5 lead. But for 7 lead we got the threshold voltage out of range which was 1.05 mV. We have mentioned before that the range of a good signal threshold voltage is 0.4 - 1 mV. So, we can see that our result for 7 lead is slightly over the range.

So, for the refined design part we tried to improve our 7-lead design so that we also get a satisfactory result. We have tried so many options. We tried to add an external filter so that our data would be more accurate. That did not work. We tried to change the gain values of the amplifiers. But that also did not fulfill our requirement. After so much trial and error we have found that if we change the value of the resistance of the summing amplifier, we can get our desired result. For our previous design the value of the resistance was 20KΩ. We changed the value to 16KΩ. After that the threshold voltage for 7-lead becomes 0.95 which is in our desired range.

Table 2.2: Comparison of Threshold Voltages for 7 Lead:

Previous 7 lead ECG design	**Refined 7 lead ECG design**
1.05mV (not good signal)	0.95mV (good signal)

From the table 2.2 it is seen that in the refined design for 7 lead ECG circuit we got good signal threshold voltage. We have successfully managed to design and simulate a 7-lead heart monitoring electrocardiogram system which gives us an accurate value.

PART-C

This part includes the implementation, finalized design, and analysis of economic viability of the project.

Chapter 3 Demonstration of Implemented Solution and Finalization of Design

3.1 Development of the prototype

In 400B we didn't describe it in detail so when we started thinking about building up our prototype, we realized that we had to change some components. After buying the necessary equipment we started to build the prototype. We have built the prototype according to the design we described in section 2.3 with slight modifications for better performance and desire result. All changes are mentioned in Table.

Table 3.1: Changed parameters and reasons for changing.

Equipment used in the prototype	Equipment mentioned in section 1.5	Specifications of the equipment used in the prototype	Reasons
ECG Sensor (AD8232)	-	• input voltage range of ±0.3V to ±2.0 V. Operating voltage range is typically between 2.0 V and 3.5 V. • **Common-Mode Rejection Ratio (CMRR)** is typically around 80 dB. • Three input pins • The cutoff frequency is typically around 40 Hz.	As we working on portable ECG using 3 lead to 7 lead that's why this sensor fits our project requirements.
Dry ECG Electrode	Dry ECG Electrode	The electrodes should have good electrical conductivity to accurately capture the ECG signals without	Dry electrodes are easier to apply since they don't have to deal with gel application and

		introducing additional noise or interference.	cleanup. This can save time during ECG procedures.
Microcontroller ESP32	Microcontroller Arduino	• Dual-core Tensilica Xtensa LX6 microprocessors clocked at up to 240 MHz. • Typically, 520 KB of SRAM for data and 8 KB of SRAM for instruction. • Integrated Bluetooth 4.2 (BLE) and Classic Bluetooth support. • Typically operates at 3.3 V.	ESP32 has built in Bluetooth module. To reduce the cost, we avoid external Bluetooth module.
DC-DC Boost Converter	-	• DC to DC step-up converter. • Input voltage: 3-32 V • Output voltage: 5-35 V	It is used for voltage regulation. For stable and precise voltage supply to ensure accurate measurements and reliable operation.
Vero Board	-	Dimension: 14.6cm Thickness: 1.1mm	For the circuit buildup strength and soldering easily, we used it.
Power Supply (Rechargeable battery)	Power Supply (Rechargeable battery)	Vout= 3.7V Iout= 700-1500 mA	The device is portable. So, we used rechargeable battery. Anyone can easily carry it.

PVC Frame	Frame	Width: 7.5 inch Height: 2.5 inch	For placement of the device and safety of the device.

Prototype (Portable Heart Monitoring Electrocardiogram Device):

For measuring the ECG, we have built a prototype according to the design that we have discussed in section 2.3. In section 2.3 we showed 7 lead ECG circuits, the prototype we made will work for 7 lead, 5 lead, and 3 lead. In 400B we made the simulation circuit by using op amp and filters but in prototype, we used ECG sensor AD8232 which has built in op amp and filter. Fully integrated single-lead ECG front end. In our prototype, AD8232 supplies current: 170 µA. Low pass filter with gain: 2.8. Single-supply operation: 3 V. We used a boost converter to step up the voltage. The input voltage may not always be constant and may fluctuate within a range. This fluctuation can damage the circuit. Thus, a DC to DC boost converter is implemented in the design. The power demand of our microcontroller is 5 to 7 volts. So we used boost converter to increase 3.7 V to 5 V. For microcontroller we used ESP32 which has built in Bluetooth module. In 400B we mentioned it will be Bluetooth control that is why we used ESP32.

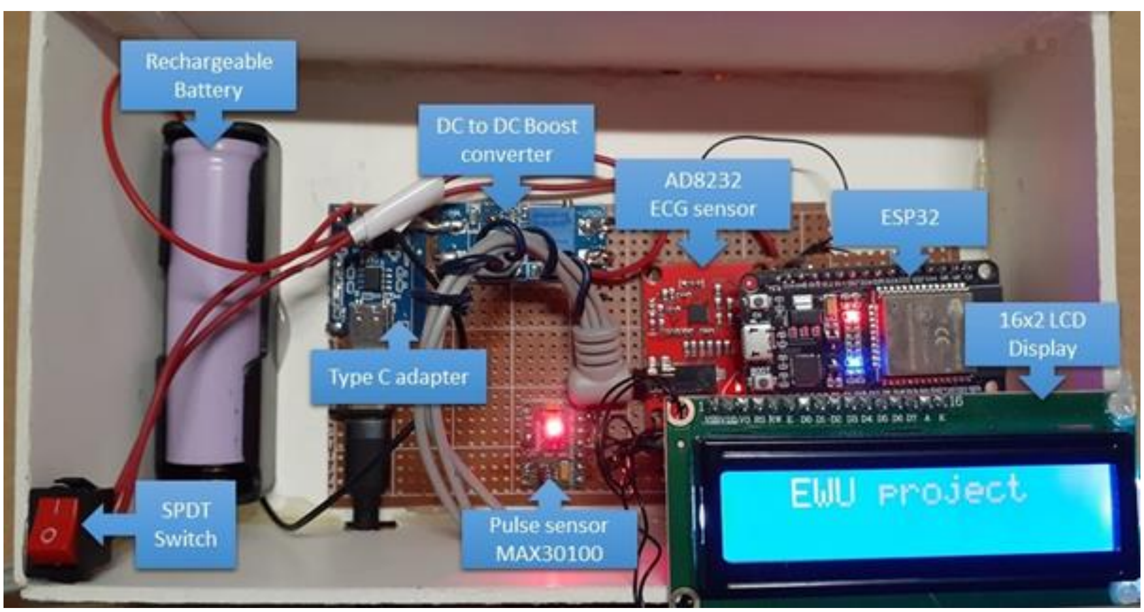


Fig.3.1: Implemented circuit of our device.

With AD8232 sensor we placed ECG dry electrodes. Electrodes are placed on the skin of the subject to sense the electrical change. These electrodes can detect the tiny electrical changes on the skin due to depolarizing and repolarizing of the heart muscles.

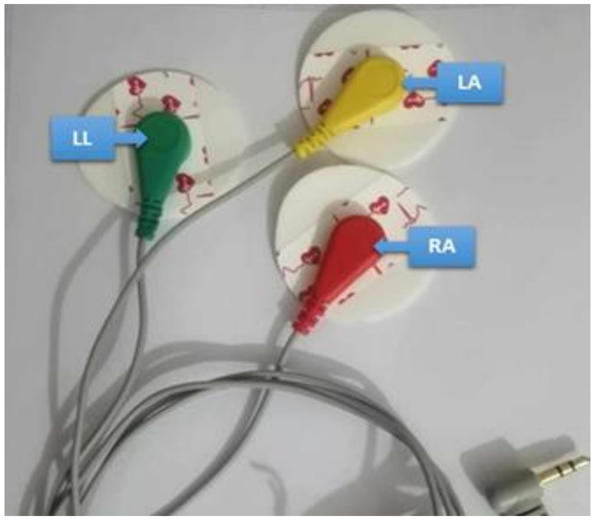


Fig.3.2: ECG Electrodes.

Fig.3.3: 3 Lead ECG Electrode Placement.

In our device, we used three electrodes. Two electrodes RA and LA are connected to the chest, and one LL is connected to different places of heart position, two chest electrodes are reference and one is used to change the lead or angle of ECG measurements. Three electrodes are used to eliminate poor connection noise.

When the electrode is placed in human body it will detect the tiny electrical changes on the skin with the help of ECG sensor AD8232 then the analog signal will be sent to microcontroller ESP32. Via Bluetooth live digital ECG data will be sent to the laptop. Firstly, we took 3 lead ECG data, then by changing one electrode placement "LL" we took 5 and 7 lead ECG data. For 5 lead we need to change the "LL" electrode 3 times. For 7 lead we need to change the "LL" electrode 5 times. All the ECG Electrode placements are shown in section 2.2.

As our device is portable so we made a frame box for placement and safety of the device.

Fig.3.4: Device frame.

It is a PVC frame. Its Width is 7.5 inches and Height is 2.5 inches.

3.2 Performance evaluation of implemented solution against design requirements

We performed certain activities to test the performance of our project after developing and completing our prototype. We did several tests to check the prototype. All the tests done are described below:

After the development of prototype for output measurement we have used a cloud server to store the live ECG data for further measurements. Our ECG can measure 3, 5, and 7 lead. For 3 lead it will show one graph. For 5 lead it will show 3 graphs. For 7 lead it will show 5 graphs. We use Python for storing data and showing ECG graph and further measurements. For testing ECG, the following work needs to be done.

Firstly, indicate the lead we want to calculate. For lead 3 press 1 because other 2 is reference. Similarly for lead 5 press 3 and lead 7 press 5. Then select the port number where the device is connected. To identify the port, we took help from PuTTy software. After entering port number start calculating ECG by press enter. Then it will start taking data and finish for 1st lead. Similarly for 2nd and 3rd will take the data, and then all the graphs will show in a single window.

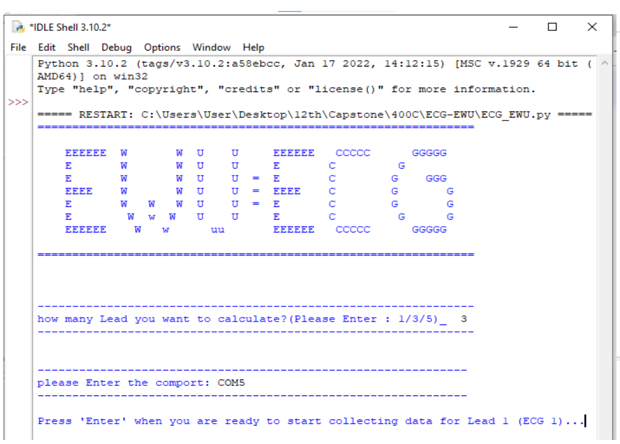
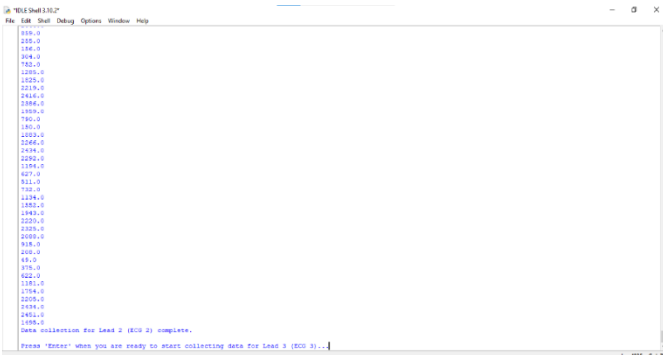


Fig.3.5: For 5 lead ECG calculation

Fig.3.6: Complete taking data for lead 1.



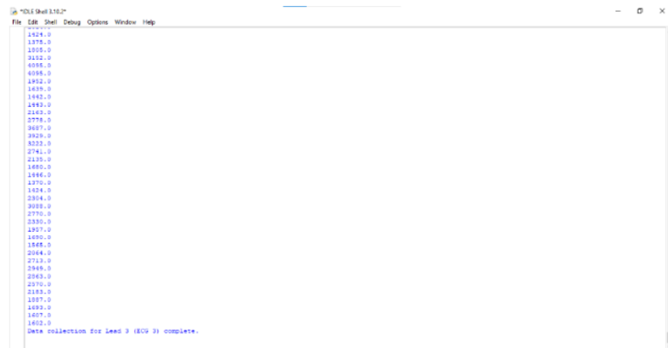


Fig.3.7: Complete taking data for lead 2. Fig.3.8: Complete taking data for lead 3.

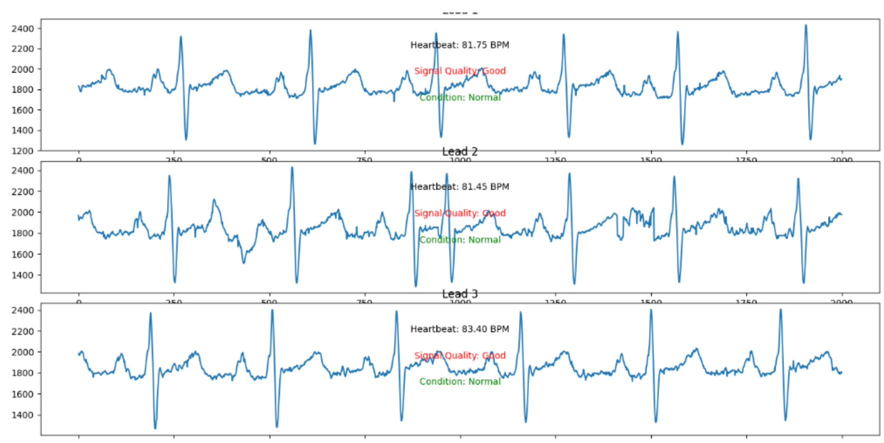


Fig.3.9: Graph for 5 lead ECG

Here in the graph window the Heartbeat BPM, signal quality and heart condition will show.

Heartbeat calculation:

$$\text{Heartbeat} = \frac{60}{Average\ R{-}R\ interval\ (in\ sec)}$$

Signal quality: If the R peak is more or less than threshold voltage then the signal will not be good. Range of threshold voltage is (0.4 to 1 mV) [20].

Heart condition: If the heartbeat is within 60 to 100 BPM [34] for resting ECG then the condition will be normal. Otherwise, abnormal conditions will show.

We have tested several ECG for different ages, states, and persons for performance evolution.

For Person-01:

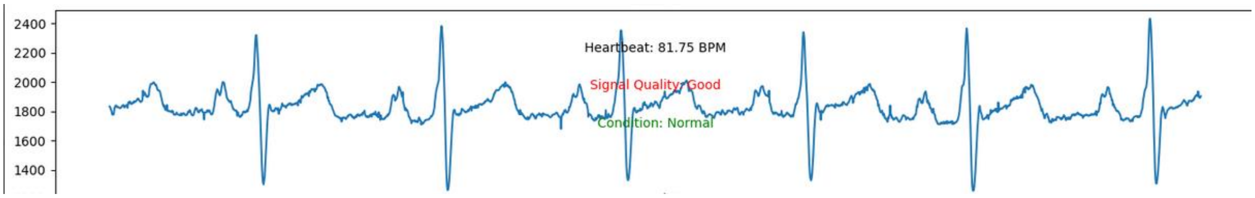


Fig.3.10: 3 Lead ECG test for person 1

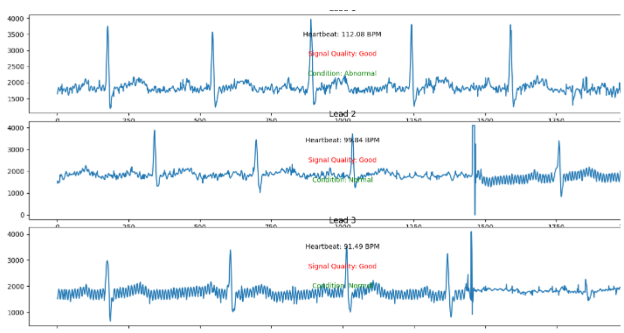


Fig.3.11: 5 Lead ECG test for person 1

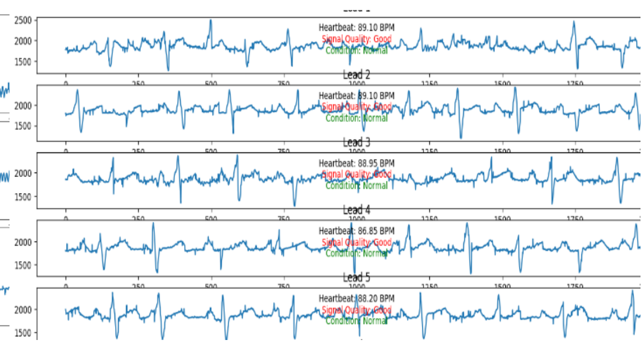


Fig.3.12: 7 Lead ECG test for person 1

Average heartbeat for 3 lead = 81.75 BPM, 5 lead = 82.2 BPM, for 7 lead = 80.28 BPM.

Person-02:

Fig.3.13: 3 Lead ECG test for person 2

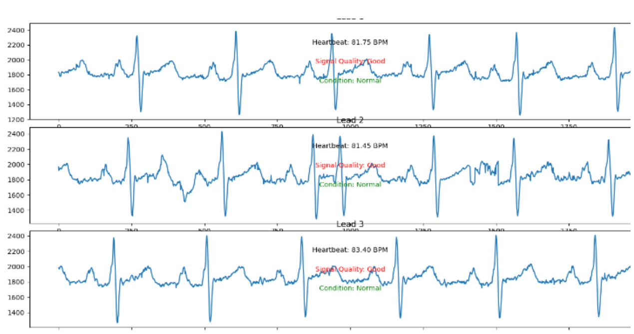


Fig.3.14: 5 Lead ECG test for person 2

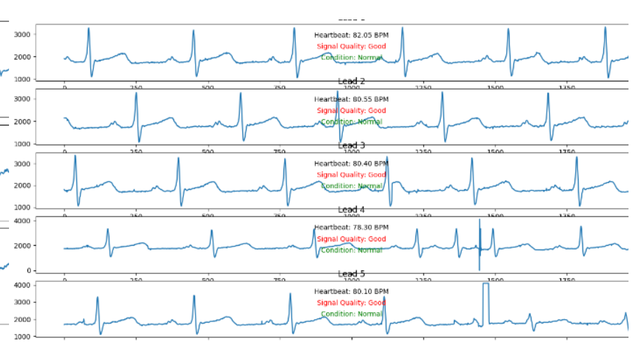


Fig.3.15: 7 Lead ECG test for person 2

Average heartbeat for 3 lead = 87.15 BPM, 5 lead = 101.14 BPM, for 7 lead = 88.44 BPM.

Person -03:

Fig.3.16 3 Lead ECG test for person 3

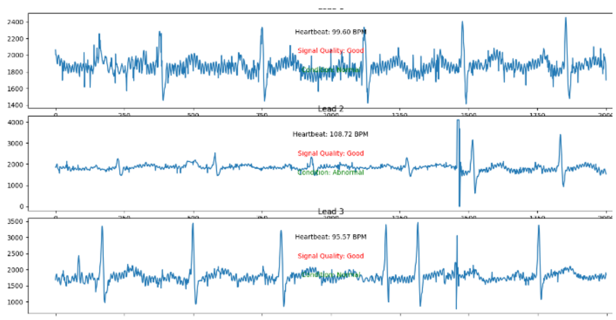


Fig.3.17: 5 Lead ECG test for person 3

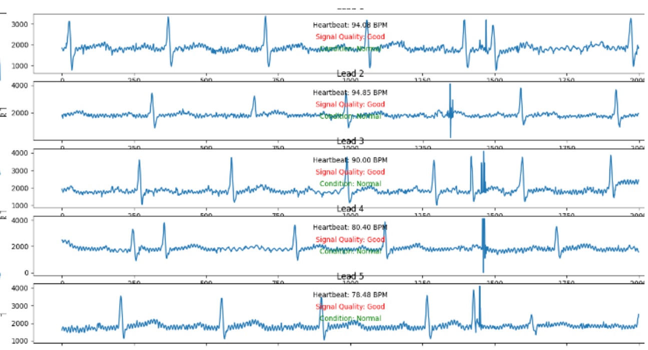


Fig.3.18: 7 Lead ECG test for person 3

Average heartbeat for 3 lead = 82.05 BPM, 5 lead = 101.42 BPM, for 7 lead = 87.562 BPM.

Person-04:

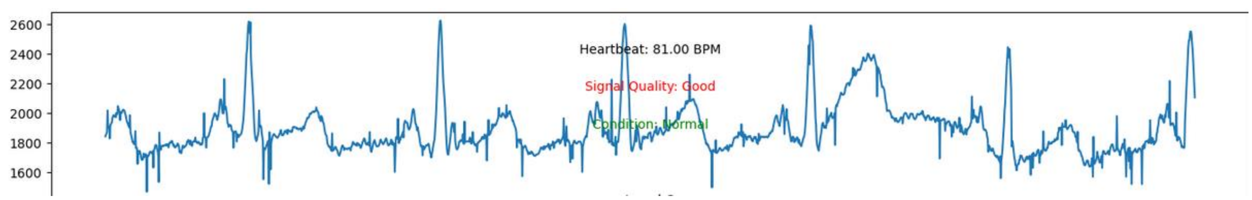


Fig.3.19: 3 Lead ECG test for person 4

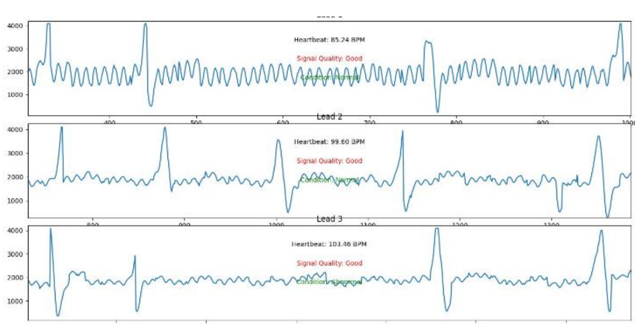


Fig.3.20: 5 Lead ECG test for person 4

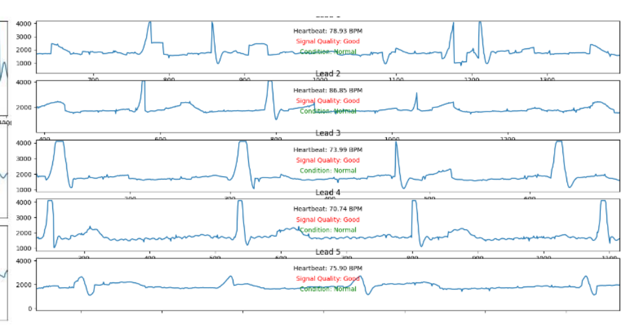


Fig.3.21: 7 Lead ECG test for person 4

Average heartbeat for 3 lead = 81 BPM, 5 lead = 96.1 BPM, for 7 lead = 77.3 BPM.

Person-05 (Abnormal Condition):

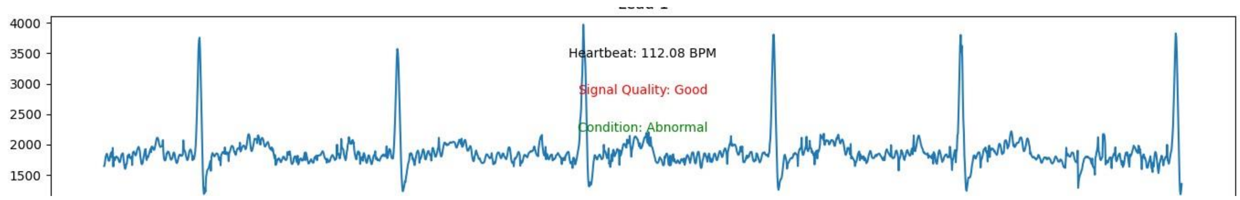


Fig.3.22: 3 Lead ECG test for p-5 (Abnormal)

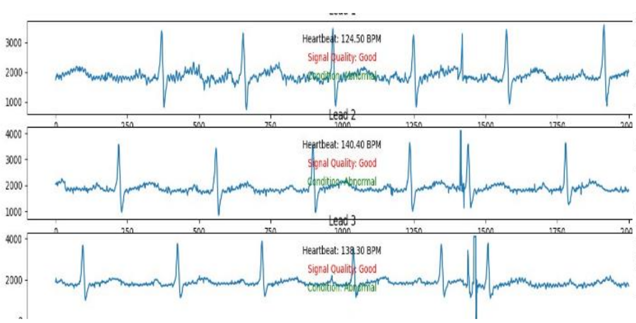


Fig.3.23: 5 Lead ECG test for p-5 (Abnormal)

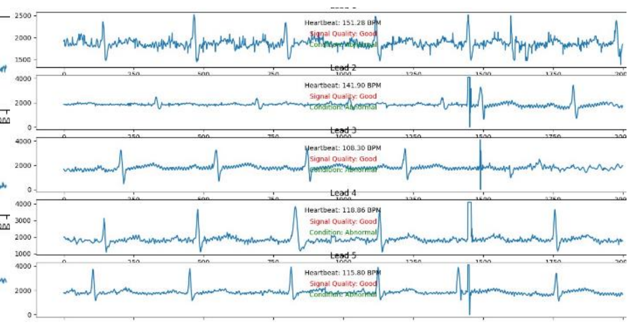


Fig.3.24: 7 Lead ECG test for p-5 (Abnormal)

Average heartbeat for 3 lead = 112.08 BPM, 5 lead = 134.4 BPM, for 7 lead = 127.228 BPM. Here, the above 5 persons' ECG graph has been shown. Number of leads are 3, 5, and 7. Prerson-05 is a heart patient. So, we can see that this person's heartbeat is very high, and the condition is abnormal. But the signal condition is good.

For the same persons' we have tested heartbeat in BPM with a pulse oximeter device to compare with our prototype.

Fig.3.25: Heartbeat tested by pulse oximeter.

Table 3.2: Comparing Prototype with Pulse Oximeter

Person	**No. of Lead**	**Prototype Output Heartbeat (BPM)**	**Prototype Average Heartbeat (BPM)**	**Pulse oximeter Heartbeat (BPM)**	**Error (%)**
01.	3	81.75	81.41	78	4.37
	5	82.2			
	7	80.28			
02.	3	87.15	92.24	93	0.82
	5	101.14			
	7	88.44			
03.	3	82.05	90.68	98	7.47
	5	101.42			
	7	88.562			
04.	3	81	84.8	87	2.53
	5	96.1			
	7	77.3			
05.	3	112.08	124.57	126	1.135
	5	134.4			
	7	127.228			

By comparing the prototype, we can see there is little error it is because of electrode quality and for lack of proper placement of electrode.

Doctor’s Evaluation:

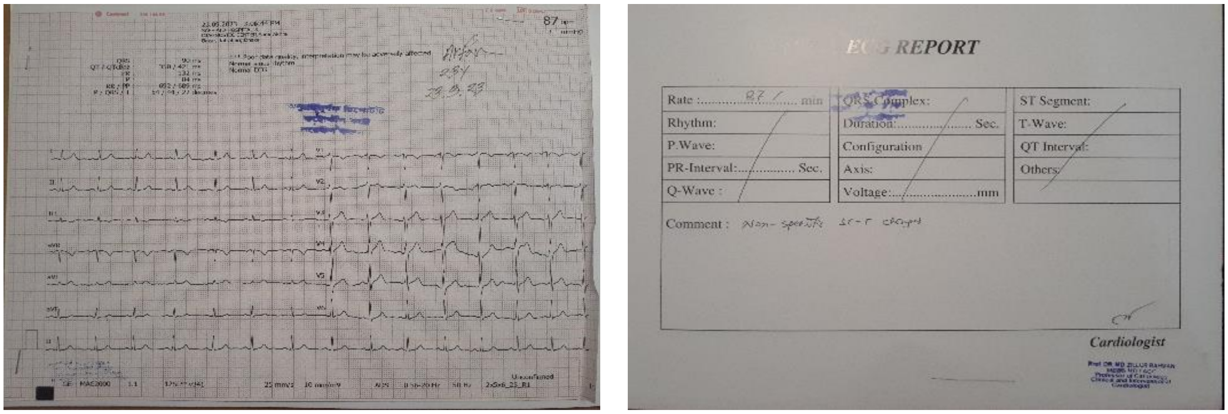


Fig.3.26: 12 Lead ECG using Traditional ECG

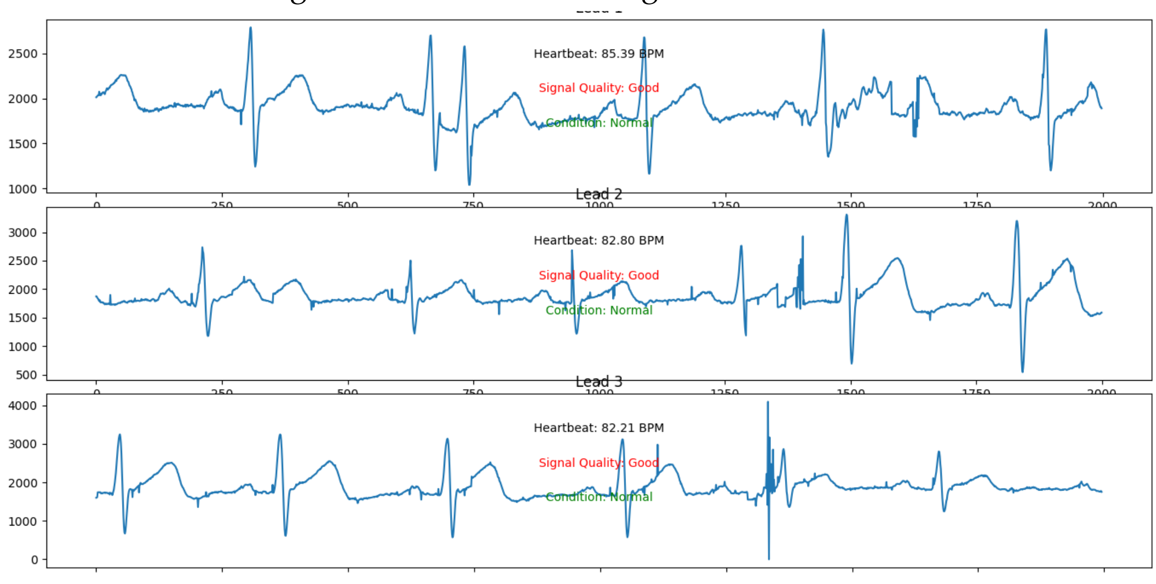


Fig.3.27: 5 Lead ECG using Portable Heart-Monitoring Electrocardiogram Device

From Fig.3.26 we can see a traditional 12 Lead ECG which has been done from Safe Aid Hospital and Diagnosis Center, Sanir Akhra by the Cardiologist, Prof. Dr. Zillur Rahman. So here, we have done a 12 Lead ECG Test (Fig.3.26) using a traditional ECG Machine. On the other hand, we have done ECG test (Fig.3.27) by 5 Lead, using our Portable Heart-Monitoring Electrocardiogram Device.

As traditional ECG has fixed 12 Lead and the heart beat is measured at the exact same time that is why we get a constant heart beat result from the report. But in our Portable Heart-Monitoring Electrocardiogram Device, we measure the result in different time using different placement of the electrodes and that is why we get different bpm values and also in that case there were some slight peak difference. We got a heart beat of 87 bpm in Fig.3.26 which is from traditional ECG because of fixed placement of 12 Lead, but from our device (Fig.3.27) we got 3 different bpm values. So, we have asked the doctor about that and the doctor told us to use the average value of the 3 bpm we got which is 83.46 bpm. We can see that we have got a slight difference in heart rate values.
From the feedback of Prof. Dr. Zillur Rahman, we found that both graphs are quite similar. As the graphs are different and also we could not perform 12 lead ECG, the similarity of the graphs may vary. And from the doctors experience and from his evaluation of the both results he concluded that our result was very much alike. As there was no mathematical or technical way to measure the similarity of the graphs we had to rely on the doctors evaluation.

3.3 Finalization of design

The simulation design proposed in 400B, and the actual implementation of the hardware prototype differ slightly. In 400B, we utilized the "Proteus" software to simulate the final circuit diagram. Because of the limitations of this particular piece of software, a few library functions were left out of software database. As a result, we needed to develop a new way to simulate our concept. Due to time constraints and for better performance, we had to simplify the design, resulting in a circuit diagram that differed from the original. The changes are outlined below:

ESP32 instead of Arduino UNO: As we mentioned before that we will use Arduino in 400B, but we have also mentioned that we will make it wireless. So, to reduce the cost we used ESP32 as it has built-in Bluetooth module.

DC to DC Boost Converter: It is used for v**oltage regulation. For** stable and precise voltage supply to ensure accurate measurements and reliable operation.

AD8232 ECG Sensor: It is a single to 20 lead ECG. We configure its filter and gain. It is fully integrated single-lead ECG front end. In our prototype, AD8232 supplies current: 170 μA. Low pass filter with gain: 2.8. Single-supply operation: 3 V.

Type-C charging module: We have used a rechargeable battery. So, to charge the device we use Type C charger.

3.4 Use of modern engineering tools

For our project implementation, we used both software and hardware. To complete the project and satisfy our objectives, we employ engineering tools. To simulate and design our system, we use Proteus Software v-8.13, Pyhton v-3.8 and Arduino IDE (Integrated Development Environment) to program microcontrollers.

Software Tools:

Arduino IDE: The Arduino IDE software configured the microcontroller(ESP32) for the sensors and other components. It is a tool for programming that uses a language similar to "C and C++." We write all the logic of how this system will operate with this software where we programmed for the microcontroller and so on[23].

Proteus v-8.13: To design the hardware of our project, we use simulation software named "Proteus 8.13". It is a toolset for electronic design. We simulated multiple sensors for our "Portable Electrocardiogram Device" design [24].

Python v-3.8: Python is used here for task automation, data analysis, and data visualization [25]. Here we can run our code and see the live data and and all the information of ECG.

PuTTY: This software helps to check which port is used for receiving data.

Hardware Tools:

ESP32: ESP32 is the microcontroller in our device. It can interface with other systems to provide Wi-Fi and Bluetooth functionality through its SPI / SDIO or I2C / UART interfaces [26]. In this project, it communicates through I2C interface.

DC to DC Boost Converter: Boost converters are a type of DC-DC switching converter that efficiently increase (step-up) the input voltage to a higher output voltage. By storing energy in an inductor during the switch-on phase and releasing it to the load during the switch-off phase [27]. It is used for voltage regulation. For stable and precise voltage supply to ensure accurate measurements and reliable operation of ECG signals.

ECG Module (AD8232): The AD8232 is an integrated signal conditioning block for ECG. It is designed to extract, amplify, and filter small biopotential signals in the presence of noisy conditions, such as those created by motion or remote electrode (Ag/AgCl) placement [28]. It is working as 3 lead ECG sensor here. By using this sensor, we can measure up to 7 leads.

ECG Electrode with Dry Hydrogel (Ag/AgCl): Dry Ag/AgCl is for ECG electrodes. It collects data from body and passes it through the other sensors.

Chapter 4 Review of Milestone Achievements and Revision of Schedule

The capstone project, named the Portable Heart Monitoring Electrocardiogram Device, was divided into three segments: 400A, 400B, and 400C, each meant to be completed sequentially. In the initial phase, 400A, our task was to construct a work plan outlining various milestones and estimating the time required to complete all tasks encompassed in 400A, 400B, and 400C. However, we encountered unexpected delays and, conversely, found ourselves achieving certain milestones ahead of schedule. As a result, we've adjusted our timetable accordingly, which is presented below.

Table 3.4.1 Revised project plan

Activity No.	Activities	Duration [Week]	Predecessor	On Time/Delay
PART-400A				
1.	Topic selection	1	-	On Time
2.	Approving the topic idea from the supervisor	1	1	On Time
3.	Literature review and research	3	2	On Time

4.	Identifying the stakeholders and preparing questionnaire for the stakeholders and collecting response from stakeholders via survey question [Milestone-1]	2	2 & 3	On Time
5.	Finalizing the project requirements	1	4	On Time
6.	Reviewing standards and codes of practice	1	5	On Time
7.	Preparing project plan [Milestone-2]	1	4,5	On Time
8.	Preparing risk assessment	1	7	On Time
9.	Identification of project impact	1	8	On Time
10.	Preparing budget and analysis of product life cycle [Milestone-3]	2	8,9	On Time
11.	Preparing project report and submission [Milestone-4]	3	3, 6, 9 & 10	On Time

PART-400B				
12.	Initial design of the project	3	11	On Time
13.	Analyzing of alternate solution and selection of the suitable one [Milestone-5]	3	12	On Time
14.	Cost optimization	2	13	On Time
15.	Verification of initial design and refine the design	3	13,14	On Time
16.	Preparing project report and submission [Milestone-6]	3	15	On Time
PART-400C				
17.	Equipment purchase	2	16	On Time
18.	Prototype development [Milestone-7]	4	17	On Time
19.	Performance evaluation	2	18	Delay
20.	Finalization of the design [Milestone-8]	2	19	Delay
21.	Preparing bill of materials cost of solution	1	20	On Time
22.	Economic analysis [Milestone-9]	1	20,21	Delay

21.	Preparing final report and presentation [Milestone-10]	3	22	Delay

Implementation delay: In the 400C phase of our project, the implementation of the Portable Heart Monitoring Electrocardiogram Device ended up consuming more time than initially anticipated. This delay stemmed from our initial receipt of defective AD8323 sensors and ESP32S Wi-Fi Bluetooth Combo modules from the suppliers. It took a considerable amount of time to identify that the sensors themselves were the source of the issue. Consequently, we invested valuable time into verifying the correctness of our connections to the AD8323 sensors and ESP32S Wi-Fi Bluetooth Combo module, along with ensuring the functionality of the electrodes. Additionally, we faced delays in acquiring suitable replacements for the faulty AD8323 sensors and ESP32S Wi-Fi Bluetooth Combo module, further contributing to the project's time overrun.

Performance evaluation delay: While assessing the heart rate detection and condition monitoring, we encountered an issue related to the threshold voltage range. Initially, it performed perfectly within the desired range. However, when switching leads, it became disconnected and yielded inconsistent data, which was subject to fluctuations. Resolving this connectivity issue and determining the optimal heart condition range for patients consumed more time than we had initially allotted. Furthermore, due to the delays encountered during the implementation phase of the Portable Heart Monitoring Electrocardiogram Device, we commenced the performance analysis later than our original schedule. This stage experienced a one-week delay.

Chapter 5 Cost of Solution and Economic Analysis

5.1 Bill of materials cost of solution

A bill of materials is a list of the raw materials, components, and finished goods or services that have been used in a project. Before we don't need to pay for the software because we used various software throughout the project for simulation and analysis. Now for developing the prototype we had to purchase different types of equipment. For that, we had to go to market, but we didn't get all the required equipment that's why we order via online few of them. The costs of each material for developing the prototype are listed below:

Table 5.1 The cost of all the equipments

No.	Equipment	Unit price (BDT)	No. of equipment required	Total (BDT)
1.	ESP32	670	1	670
2.	ECG Sensor (AD8232)	850	1	850
3.	Display(16╳2)	170	1	170
4.	I2C Adapter	140	1	140
5.	C-type Charging Module(TP4656)	60	1	60
6.	SPDT Switch	10	1	10
7.	Battery	100	2	200
8	Battery Casing	30	1	30
10.	Battery Charger	200	1	200
11.	Veroboard	40	1	40

12.	DC-DC Boost Converter	100	1	100
13.	Charging Port	40	1	40
14.	Casing	180	1	180
15.	Electrode	500	4	2000
16.	Cable	300	1	300
17.	Wire	100	1	100
18.	Soldering Kit	950	1	950
19.	Glue Gun	240	1	240
20.	Bluetooth Adapter(For PC)	300	1	300
21.	Multimeter	470	1	470
22	Pulse Sensor MAX30100	370	1	370
Total				**7,420**

7,420taka is needed to implement our portable heart-monitoring Electrocardiogram device. This price is the retail price of today's market. The wholesale price would be different from the retail price

So, wholesale price = (Retail price) ×0.6 [29]
= (7,420) × 0.6
= 4,452 Taka

5.2 Economic analysis

Here we have done our economic analysis to see whether the project will be profitable or not. Any system that must be analyzed in an economical way. To target businesses and sell the product on the future market, we need a complete economic analysis which quantifies the private and social costs and benefits of a project to the society or economy while considering the opportunity costs of resources used. The monthly estimation of operating and maintenance costs of our system is given below,

Table 5.2 Operational & Maintaining Cost

Designation	Quantity	Salary per Month (BDT)	Salary per Year (BDT)
Manager	1	40,000	4,80000
Engineer (R&D Department)	2	35,000	4,20000
Accountant	2	30,000	3,60000
Technician (Assemble)	5	18,000	2,16000
Salesperson	3	15,000	1,80000
Security	2	10,000	1,20000
Total	**15**	**1,48,000**	**17,76,000**

Table 5.3 Utility Cost

Description	Unit	Expenditure per month (BDT)	Expenditure per year (BDT)
Office Rent	1	40,000	4,80,000
Utility Bills	-	20,000	2,40,000
Marketing Cost	-	80,000	9,60,000
Meal & Refreshments	15	1,500	3,24,000

Others	-	2,000	24,000
Total			**20,28,000**

Initially, we intend to produce 5000 units per year.

Total annual expenditure = O&M Cost + Production cost of 5000 pieces
= 17,76,000 + 20,28,000 + (4,452× 5000) taka/year
= **2,60,64,000 taka/year**

Unit Selling Price = 9000Taka
Annual sell = 5000 units × 9000 Taka
= 45,000,000 Taka

The lifespan of our device depends on the sensors mainly. Our ESP32 module lifespan is around 5 to 12 years or more [30] depending on several factors. Ecg electrodes (Ag/AgCl) are around 1 time use.Ad8232 is around 12 months [31]. So, observing the overall lifespan of the device we can use, n=5.

Present Value Function (PVF):
Present Value Function is used to know the value of the money in future in today's price. Here, the discount rate has been taken from Bangladesh Bank [32].

So, d= 5% and n=5 years

Present Value Function: $\boldsymbol{PVF(d,n)} = \frac{(1+\mathrm{d})^{n}-1}{\mathrm{d}(1+\mathrm{d})^{n}}$

$= \frac{(1+0.05)^{5}-1}{0.05(1+0.05)^{5}}$ years

= **4.33 years**

Interest rate (i) = 6%, which is taken from Al-Arafah Islami Bank[33].

<u>The Capital Recovery Factor (CRF):</u>

CRF (i, n) $= \frac{\mathrm{i}(1+\mathrm{i})^5}{\mathrm{i}(1+\mathrm{i})^5 - 1}$

So, CRF (6%, 5) $\frac{(1+0.05)^5 - 1}{0.05(1+0.05)^5}$

= 0. 24

Annual loan Payment, $A = P \times CRF(i, n)$

Where, P is at the annual expense which is = **2,60,64,000 Taka**

So, A = 2,76,24,000 tk × 0.24 = **66,29,760 Taka**

Annual saving ΔA =45,000,000 – 66,29,760 – 2,60,64,000 = **1,23,06,240 Taka**

First cost, ΔP = 2,76,24,000 Taka

Simple Payback Period = $\frac{\Delta P}{\Delta A}$

$= \frac{2,76,24,000}{1,23,06,240}$ years

= **2.24 years**

<u>Net Present Value (NPV):</u>

NPV = ΔA × PVF (d, n) – ΔP

= (1,23,06,240 × 4.33) - 2,76,24,000

= 2,56,62,019.2 Taka

As the NPV is positive, so our business plan on this project is profitable.

<u>Internal Rate of Return (IRR) :</u>

The Figure of Present Value Function to help Estimate the Internal Rate of Return (IRR) is given below. The Internal Rate of Return (IRR) is a useful calculation that determines the value of a project. The figure contains a Chart to estimate the Internal Rate of Return[34]. The following chart contains the IRR:

IRR (r, n) =$(1 + \mathrm{r})^n$

Life (years)	9%	11%	13%	15%	17%	19%	21%	23%	25%	27%	29%	31%	33%	35%	37%	39%
1	0.92	0.90	0.88	0.87	0.85	0.84	0.83	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.73	0.72
2	1.76	1.71	1.67	1.63	1.59	1.55	1.51	1.47	1.44	1.41	1.38	1.35	1.32	1.29	1.26	1.24
3	2.53	2.44	2.36	2.28	2.21	2.14	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.70	1.65	1.61
4	3.24	3.10	2.97	2.85	2.74	2.64	2.54	2.45	2.36	2.28	2.20	2.13	2.06	2.00	1.94	1.88
5	3.89	3.70	3.52	3.35	3.20	3.06	2.93	2.80	2.69	2.58	2.48	2.39	2.30	2.22	2.14	2.07
6	4.49	4.23	4.00	3.78	3.59	3.41	3.24	3.09	2.95	2.82	2.70	2.59	2.48	2.39	2.29	2.21
7	5.03	4.71	4.42	4.16	3.92	3.71	3.51	3.33	3.16	3.01	2.87	2.74	2.62	2.51	2.40	2.31
8	5.53	5.15	4.80	4.49	4.21	3.95	3.73	3.52	3.33	3.16	3.00	2.85	2.72	2.60	2.48	2.38
9	6.00	5.54	5.13	4.77	4.45	4.16	3.91	3.67	3.46	3.27	3.10	2.94	2.80	2.67	2.54	2.43
10	6.42	5.89	5.43	5.02	4.66	4.34	4.05	3.80	3.57	3.36	3.18	3.01	2.86	2.72	2.59	2.47
15	8.06	7.19	6.46	5.85	5.32	4.88	4.49	4.15	3.86	3.60	3.37	3.17	2.99	2.83	2.68	2.55
20	9.13	7.96	7.02	6.26	5.63	5.10	4.66	4.28	3.95	3.67	3.43	3.21	3.02	2.85	2.70	2.56
25	9.82	8.42	7.33	6.46	5.77	5.20	4.72	4.32	3.98	3.69	3.44	3.22	3.03	2.86	2.70	2.56
30	10.27	8.69	7.50	6.57	5.83	5.23	4.75	4.34	4.00	3.70	3.45	3.22	3.03	2.86	2.70	2.56

[a]Enter the row corresponding to project life, and move across until values close to the simple payback period, $\Delta P/\Delta A$, are reached. IRR is the interest rate in that column. For example, a 10-year project with a 5-year payback has an internal rate of return of just over 15%.

Fig. 5.1 Chart of the estimate Internal Rate of Return

Here, the simple payback period is 2.24 which is near to 2.22 in the above chart. So, according to the chart in (Figure 5.1), we get the IRR≈35% for n = 5 years.

So, the project solution would provide returns on investment because the IRR is positive.

Chapter 6 Conclusion

6.1 Verification of complex engineering problem

The project, Portable Heart Monitoring Electrocardiogram Device satisfies 4 complex engineering problems. In this section of 400C, we will now verify them.

P1: Depth of Required Knowledge

K4: (Engineering Specialist Knowledge):

In the Portable Heart Monitoring Electrocardiogram Device, we required a microcontroller to integrate the AD8323 sensors, ESP32S Wi-Fi Bluetooth Combo module, Charging port module, heart rate sensor, and display. It ensures smooth communication and coordination among these components, managing data inputs, wireless connectivity, power regulation, heart rate monitoring, and real-time data visualization. The microcontroller serves as the central control hub, optimizing the functionality and integration of this comprehensive sensor and display system.

K5: (Engineering Design Knowledge):

We've crafted a unique circuit layout tailored to our needs, optimizing functionality. Complementing this ingenuity, we've ingeniously fashioned a portable, user-friendly box, ensuring convenient transportability. Our creative approach marries purposeful design with practicality.

K6: (Knowledge of Modern Engineering Tools)

We used modern engineering tools in the execution process of a Portable Heart Monitoring Electrocardiogram Device. We designed a Portable Heart Monitoring Electrocardiogram Device Proteus software that facilitated the design of the circuit's schematic layout. Also, we harnessed Arduino code and Python software, resulting in a seamless blend of technology for its operational prowess.

K8: (Research Knowledge):

Throughout the project's journey, our reliance on research knowledge was unwavering. Whether determining the Portable Heart Monitoring Electrocardiogram Device's dimensions or selecting sensors and mechanisms to segregate the Electrocardiogram Device, we delved into numerous research papers for insights and implementation. Additionally, we assessed alternative solutions from research sources to identify the most suitable approach for our project.

P3: Depth of Analysis Required

During the project implementation, we explored various approaches for executing the project. Within these approaches, we conducted a thorough cost evaluation to determine their viability. Additionally, we assessed the performance and quality of the sensors, including the AD8323 sensors and the ESP32S Wi-Fi Bluetooth Combo module intended for the Portable Heart Monitoring Electrocardiogram Device. Our selection was based on compatibility and effectiveness for our project's requirements.

P4: Familiarity of issues

Our project, the Portable Heart Monitoring Electrocardiogram Device, delves into biomedicine and data analysis. By comprehending the human cardiovascular system, we've designed a device that accurately captures heart signals using AD8323 sensors. This data is analyzed using advanced algorithms, enabling us to detect irregularities and anomalies. Our integrated approach enhances cardiac health monitoring, offering valuable insights for early detection and proactive management.

P6. Extent of Stakeholder Involvement and Conflicting Requirements

Our capstone project, Portable Heart Monitoring Electrocardiogram Device, involves quite a diverse pool of stakeholders like Cardiac Patient, of the country the Portable Heart Monitoring Electrocardiogram Device are placed in and the Cardiac Patient,

Doctors and general people of the country. Diagnostics centers are also an important stakeholder in our project as we intend to work with them. However, all the stakeholders did not have the same requirements and demands from our project. For example, in general, people wanted to have the smoothest user experience while interacting with the

Portable Heart Monitoring Electrocardiogram Device and wanted the device to have the advanced features. On the other hand, the doctor and diagnostics center we interviewed emphasized the device to be cost effective and wanted the device to be integrated with the already established cleaning infrastructure of the country.

6.2 Meeting the project objectives

Our project, the Portable Heart Monitoring Electrocardiogram Device, was meticulously designed to meet specific objectives. Here's how we ensured that each goal was achieved:

1. Accurate Heart Rate Monitoring: The primary objective was to create a device capable of accurately monitoring heart rates. We employed state-of-the-art AD8323 sensors and implemented precise algorithms to ensure real-time heart rate tracking. Through extensive testing, we validated that our device consistently provided accurate heart rate data.

2. Detection of Cardiac Abnormalities: Detecting irregularities in heart rhythms was another crucial aim. By analyzing electrocardiogram (ECG) signals in-depth, our device can identify conditions such as arrhythmias and anomalies. This helps in early detection and prompt medical intervention when needed.

3. User-Friendly Design: We aimed to make our device accessible to a wide range of users. We ensured a user-friendly design with a simple interface, making it easy for individuals of all ages to operate. Safety and comfort were prioritized in the device's physical design and electrode materials.

4. Data Analysis and Insights: Our objective was to provide valuable insights into cardiac health. Through complex data analysis algorithms, we process ECG data, comparing it with historical information to identify trends and anomalies. This empowers both users and healthcare professionals with actionable insights for proactive health management.

5. Connectivity and Remote Monitoring: To expand the device's usability, we integrated the ESP32S Wi-Fi Bluetooth Combo module. This feature enables seamless data transmission to remote monitoring systems. Thus, users can share their cardiac data with healthcare providers, ensuring timely medical advice and enhanced patient care.

Further Development: The developed prototype system already serves its purpose. However, there are a few numbers of advances that can be made to make the system even better and more user-friendly. Following are the future development plan:

- Develop a smartphone application so that the device becomes more user friendly.
- Convert the circuit into PCB for better accuracy.
- Upgrade our system to measure the pressure along with symptoms.
- Developing the circuit so that 12 lead ECG can be measured.

APPENDIX A. ACTIVITY CHART

Part-A

Date	Participants	Activity Description	Approx. hrs. spent
25.08.2022	Everyone	Selected a topic which is suitable for the Capstone project.	10
28.08.2022	Everyone	Contacted the supervisor and approved the topic idea.	1
27.10.2022	Everyone	Prepared presentation slides to prove that our project has social relevance and is a complex engineering and design problem.	4
3.11.2022	Everyone	Identify the stakeholders.	1
13.11.2022	Everyone	Prepared questionnaires for the stakeholders.	2
11.12.2022	Everyone	Proceeding with the stakeholder survey	5
07.12.2022	Everyone	Finalizing the requirements	4

10.12.2022	Everyone	Literature Review.	24
15.12.2022	Arfan ahmed niloy	Identified the project's impact on society, the effect on environment, sustainability, health, and safety issues.	4
17.12.2022	Arfan ahmed niloy and MD abir hassan	Reviewing standards and codes of practice.	4
19.12.2022	Everyone	Project plan and risk management.	12
23.12.2022	Arfan ahmed niloy and Tahmid Inam	Identifying required resources and budget and Analysis project product lifecycle	3
28.12.2022	Everyone	Preparing Project concept and Proposal report	10

Part-B

Date	Participants	Activity Description	Approx. hrs. spent
18.02.2023	Everyone	First meeting with Supervisor for EEE400B.	0.2
20.02.2023	Everyone	Finding a perimeter for every alternate solution.	6

27.02.2023	Arfan Ahmed Niloy and Md. Abir hassan	Calculating alternate solutions perimeter.	5
08.03.2023	Everyone	Second meeting with Supervisor regarding sensors.	0.2
18.03.2023	Everyone	Comparing solutions and finding a final approach.	8
27.03.2023	Everyone	Calculating required perimeter for finalized approach.	5
10.04.2023	Arfan ahmed niloy and Kazi sadia	Preparing functional design.	12
21.04.2023	Everyone	Preparing Project Report.	20

Part-C

Date	Participants	Activity Description	Approx. hrs. spent
12.06.2023	Everyone	Meeting with supervisor	0.2
19.06.2023	Everyone	Find out equipment availability	4
26.06.2023	Everyone	Preparation of draft design	9
30.06.2023	Arfan ahmed niloy and Tahmid Inam	Purchase equipment	4
09.07.2023	Everyone	Meeting with supervisor	0.1
19.07.2023	Everyone	Meeting with supervisor	0.15
26.07.2023	Everyone	Meeting with supervisor	0.1

05.08.2023	Everyone	Implementation	60
08.08.2023	Everyone	Performance evaluation	5
16.08.2023	Everyone	Meeting with supervisor	0.2
29.08.2023	Kazi Sadia and Arfan Ahmed Niloy	Prepared cost of solution and Economic analysis	12
30.08.2023	Arfan Ahmed Niloy and Tahmid Inam	Meeting with supervisor	0.1
20.09.2023	Everyone	Prototype demonstration	0.2
20.09.2023	Everyone	Presentation of final report	20

APPENDIX B. OTHER TECHNICAL DETAILS

Questionnaires for the stakeholders

Your response to this survey is solely intended for educational purposes and nothing else. Your identity will be strictly hidden and none of this information will be delivered to anyone for commercial purposes or anything of that sort. You have complete freedom while providing these answers and the surveyors will not try to bias you into giving any specific answer.

Survey by:

Arfan Ahmed Niloy

Md Abir Hassan

Tahmid Inam Zasem

Kazi Sadia,

East West University

Department of EEE

1.Have you ever done ECG? *

- Yes
- No

2.If yes how was your experience? *

- Cheap
- Comfortable
- Costly
- Uncomfortable
- Neutral

3.Do you have any cardiac patients in your family? *

- Yes
- No

5.If yes, how many times do you or your patients need an ECG test in a month? *

- 1 to 2 times
- 3 to 4 times
- 5+ times
- Neutral

6.How much do you have to pay for per ECG test? *

- 200 – 500 taka
- 500 – 1000 taka
- 1000 + taka
- Neutral

7.Have you ever heard about portable ECG machine? *

- Yes
- No

8.Do you feel the necessity of a portable ECG machine that can be carried anywhere?

- Yes
- No
- Neutral

9.How do you want to see your ECG data from a portable ECG machine? *

- Mark only one oval.
- Device display
- Website
- App

10.What type of battery would you prefer for portable ECG machines? *

- Rechargeable
- Non-rechargeable

11.What type of electrode (probe) do you want to use in a portable ECG machine? *

- Wet Electrode (Gel)

- Dry Electrode (Without Gel)
- Neutral

12.How many leads do you want to check of your heart? *

- 3
- 5
- 7
- 12
- Neutral

13.What price range do you think is suitable for such a device? *

- 4-8K
- 8-12K
- 12-17K

14.If you have experience using a portable ECG machine, how do you want to rate it?

- *****
- ****
- ***
- **
- *
- Neutral

15.If you ever used a portable ECG machine, what improvement would you suggest?

Write your opinion :

APPENDIX C. JUSTIFICATION OF COMPLEX ENGINEERING PROBLEM

This table prepared in EEE400A justifies the proposed project as a complex engineering problem

Attribute	**Complex Engineering Problems** have characteristic P1 and some or all of P2 to P7:	Covered in the project? (Y/N)	Explain/justify
Depth of knowledge required	P1: Cannot be resolved without in-depth engineering knowledge at the level of one or more of K3, K4, K5, K6 or K8, which allows for a fundamentals-based, first principles analytical approach	Y	By achieving K4, K5, K6, K8 we have covered P1. For this project we have to use a microcontroller. Also, our design is an embedded system, it satisfies Engineering Specialized Knowledge (K4). As we are making an engineering design this satisfies engineering design knowledge(K5). We will have to use MATLAB/Proteus for simulation purposes which satisfies knowledge of Modern Engineering Tools (K6) and lastly, we have accrued Research Knowledge (K8) by doing literature reviews. studying different ranges of outputs from different sensors and comparing between sensors.
Range of conflicting requirements	P2: Involves wide-ranging or conflicting technical, engineering and other issues	N	
Depth of analysis required	P3: There is no obvious solution, and abstract thinking and originality in analysis are required to formulate suitable models	Y	As our project is an open-ended design problem so there are numerous approaches, we can take to complete the project also we will need to balance multiple variables which covers P3
Familiarity of issues	P4: Involves infrequently encountered issues	Y	As our project is bio medical based, we need biomedical knowledge and data analysis concept
Extent of applicable codes	P5: Are outside problems encompassed by standards and codes of practice for professional engineering	N	
Extent of stakeholder involvement and conflicting requirements	P6: Involves diverse groups of stakeholders with widely varying needs	Y	Our stakeholders are Doctor, Nurse, Diagnostics center & general people. So, there might be diversity in their opinion. For example, General People might want to compromise some

			functionalities to reduce the cost. On the other hand, the Doctor will want a better system regardless of the cost. So there has a diversity in their opinion. Which satisfies P6
Interdependence	P7: High level problems including many component parts or sub-problems	N	

APPENDIX D. JUSTIFICATION OF COMPLEX ENGINEERING ACTIVITIES

This table prepared in EEE400C describes the complex engineering activities in the project

Attribute	**Complex activities mean (engineering) activities or projects that have some or all of the following characteristics:**	**Covered in the project? (Y/N)**	**Explain**
Range or resources	A1: Involves the use of diverse resources (for this purpose, resources include people, money, equipment, materials, information and technologies)	Y	We have used different types of resources in our project, such as: different types of sensors and modules [AD832 ESP32 WIFI & BLUETOOTH MODULE, ELECTRODE BATTERY] we have also used boost converter for power. We have used some modern engineering software like: Proteus and Python MATLAB. We also invested our time, money, and effort into the project.
Level of interaction	A2: Requires resolution of significant problems arising from interactions among wide-ranging or conflicting technical, engineering, or other issues	Y	Initially we wanted to make an electrocardiogram device with a capacity of up to 7 lead with 3 lead compartments. However, during 400C we decided to have 3 compartments which means the size of the electrocardiogram device has to be larger. Secondly, we wanted to use a box for device protection.
Innovation	A3: Involves creative use of engineering principles and research-based knowledge in novel ways	Y	We can see regular ECG machines everywhere in the hospital. Usually, people aren't motivated to use it. To mitigate this problem, we are introducing a new type of electrocardiogram device which will give up to 7 lead data the user for measuring and the data shown in display converted into graphs. We believe the best way to motivate people is to use them with something. As a result, people will be motivated to use our electrocardiogram device which will eventually result in cardiac patient places which we dreamt of.

Consequences for society and the environment	A4: Has significant consequences in a range of contexts; characterized by difficulty of prediction and mitigation	Y	Our device will have positive consequences for society and the medical side. We know cardiac patients need this. It will remain for a long period of time. Our device will give an ECG graph to the user for use in our electrocardiogram device as they are getting accurate data, they will be more motivated to use it, Also, people will adopt the habit of using proper management of this device.
Familiarity	A5: Can extend beyond previous experiences by applying principles-based approaches	N	

APPENDIX E. RUBRICS

Rubrics for EEE400

Table 1: Rubrics for assessment of PO9 (Individual work and teamwork)

Performance indicators	Outstanding (9 – 10)	Good (7 – 8)	Satisfactory (6)	Unsatisfactory (0 – 5)
Individual skills	Actively participates in group discussions and decision making, contributes useful ideas, completes assigned responsibilities thoroughly on time	Participates in group discussions and decision making, contributes ideas, completes assigned responsibilities mostly on time	Somewhat participates in group discussions and decision making, sometimes contributes ideas, completes some of the assigned responsibilities on time	Does not participate in group discussions and decision making, does not contribute relevant ideas, does not complete assigned responsibilities on time
Team skills	Always collaborates with others, always promotes constructive team atmosphere, always identifies and responds to conflicts promptly and positively	Usually collaborates with others, usually promotes constructive team atmosphere, usually identifies and responds to conflicts positively	Sometimes collaborates with others, sometimes promotes constructive team atmosphere, sometimes identifies and responds to conflicts positively	Does not collaborate with others, does not promote constructive team atmosphere, does not identify and respond to conflicts
Leadership skills	Always provides direction to achieve goals, always respects and listens to other members, always plans for improvement, always motivates others	Usually provides direction to achieve goals, usually respects and listens to other members, usually plans for improvement, usually motivates others	Sometimes provides direction to achieve goals, sometimes respects and listens to other members, sometimes plans for improvement, sometimes motivates others	Does not provide direction to achieve goals, does not respect and listen to other members, does not plan for improvement, does not motivate others
Multidisciplinary activities	Fully understands and appreciates the multidisciplinary nature of the project activities, shows interests and participates in activities in disciplines outside of own	Mostly understands and appreciates the multidisciplinary nature of the project activities, participates in activities in disciplines outside of own	Somewhat understands and appreciates the multidisciplinary nature of the project activities, participates in some activities in disciplines outside of own	Does not understand or appreciate the multidisciplinary nature of the project activities, does not participate in activities in disciplines outside of own

Table 2: Rubrics for assessment of PO8 (Ethics)

Performance indicators	Outstanding (9 – 10)	Good (7 – 8)	Satisfactory (6)	Unsatisfactory (0 – 5)
Equity	Always approaches situations with consideration of equity, always behaves inclusively	Mostly approaches situations with consideration of equity, mostly behaves inclusively	Sometimes approaches situations with consideration of equity, Sometimes behaves inclusively	Does not approach situations with consideration of equity, does not behave inclusively
Accountability	Always understands about accountability and personal responsibility, always assumes responsibility of own actions	Mostly understands about accountability and personal responsibility, mostly assumes responsibility of own actions	Sometimes understands about accountability and personal responsibility, sometimes assumes responsibility of own actions	Does not understand about accountability and personal responsibility, does not assume responsibility of own actions
Proper use of others' works	Always recognizes the need for due acknowledgment of others' works, intellectual property and copyrighted materials, and acts accordingly	Mostly recognizes the need for due acknowledgment of others' works, intellectual property and copyrighted materials, and mostly acts accordingly	Sometimes recognizes the need for due acknowledgment of others' works, intellectual property and copyrighted materials, and sometimes acts accordingly	Does not recognize the need for due acknowledgment of others' works, intellectual property and copyrighted materials, and does not act accordingly
Professionalism	Fully understands the role of the engineer in protecting public interests, fully understands and is aware of relevant codes of ethics	Mostly understands the role of the engineer in protecting public interests, mostly understands and is mostly aware of relevant codes of ethics	Somewhat understands the role of the engineer in protecting public interests, somewhat understands and is somewhat aware of relevant codes of ethics	Does not understand the role of the engineer in protecting public interests, does not understand or is not aware of relevant codes of ethics

Rubrics for EEE400A

Table EEE400A: Rubrics for assessment of the project concept and proposal

Performance indicators	Outstanding (9 – 10)	Good (7 – 8)	Satisfactory (6)	Unsatisfactory (0 – 5)
PCP_PI1: Able to identify a suitable complex engineering design problem (1a) [sec-1.1, Appendix C] **(CO1/PO12, P1)**	Demonstrates an ability to explore a topic thoroughly, and to identify a suitable complex engineering problem	Demonstrates an ability to explore a topic, and to identify a reasonably suitable complex engineering problem	Demonstrates an ability to somewhat explore a topic, and to identify a somewhat suitable complex engineering problem	Demonstrates minimal or no ability to explore a topic, or to identify a suitable complex engineering problem
PCP_PI2: Engages to stay up to date on the relevant topic (2b) [sec-1.2] **(CO1/PO12, P1)**	Demonstrates thorough engagement to stay up to date on the relevant topic	Demonstrates engagement to stay up to date on the relevant topic	Demonstrates some engagement to stay up to date on the relevant topic	Demonstrates minimal or no engagement to stay up to date on the relevant topic
PCP_PI3: Identifies the regulatory requirements, standards, and codes of practice (2a) [sec-1.3] **(CO2/PO3, P5)**	Identifies all the relevant regulatory requirements, standards, and codes of practice	Identifies most of the relevant regulatory requirements, standards, and codes of practice	Identifies some of the relevant regulatory requirements, standards, and codes of practice	Does not identify any of the relevant regulatory requirements, standards, and codes of practice
PCP_PI4: Explains the objectives, project requirements and constraints of the solution considering the expectations of the stakeholders (2c) [sec-1.4, 1.5] **(CO2/PO3, P2, P6)**	Clearly explains the objectives, project requirements and constraints taking into account all the expectations of the stakeholders	Explains the objectives, project requirements and constraints taking into account most of the expectations of the stakeholders	Somewhat explains the objectives, project requirements and constraints fully taking into account some the expectations of the stakeholders	Does not explain the objectives, project requirements and constraints and/or does not take into account any expectation of the stakeholders
PCP_PI5: Prepares project management plan, setting up milestones and considering risks and contingencies (2d) [sec-1.6.1, 1.6.2] **(CO3/PO11)**	Prepares a comprehensive project management plan, clearly sets up milestones, thoroughly considers risks and contingencies	Prepares a project management plan, sets up milestones, considers risks and contingencies	Prepares a project management plan, sets up a few milestones, attempts to considers risks and contingencies	Prepares a unclear/incomplete project management plan, does not set up milestones, does not consider risks and contingencies
PCP_PI6: Identifies required resources and prepares a realistic budget (2e, 2g) [sec-1.6.3] **(CO3/PO11)**	Identifies all resources and prepares budget that covers all applicable areas of the project including room for contingency	Identifies most resources and prepares budget that covers most applicable areas of the project including room for contingency	Identifies some resources and prepares budget that covers some applicable areas of the project	Cannot identify resources and cannot prepare a budget addressing major applicable areas of the project

PCP_PI7: Explains how to sustain and maintain the product/service in business if the solution is successfully commercialized. (2h) [sec-1.7]	Clearly explains how to sustain and maintain the product/service in business if the solution is successfully commercialized.	Explains how to sustain and maintain the product/service in business if the solution is successfully commercialized.	Somewhat explains how to sustain and maintain the product/service in business if the solution is successfully commercialized.	Does not explain how to sustain and maintain the product/service in business if the solution is successfully commercialized.
PCP_PI8: Considers the impact of the solution on society including health, safety, cultural, and legal issues (2f) [sec-1.8.1, 1.8.3] **(CO4/PO6)**	Considers all the impacts on society including health, safety, cultural and legal issues	Considers most of the impacts on society including health, safety, cultural and legal issues	Considers some of the impacts on society including health, safety, cultural and legal issues	Does not consider any impact on society including health, safety, cultural and legal issues
PCP_PI9: Considers the impact of the solution on environment and sustainability over the entire product life cycle. Proposes mitigating solution if needed. (2f) [sec-1.8.2] **(CO5/PO7)**	Considers all the impacts on environment and sustainability. If necessary, proposes solutions to mitigate negative impact	Considers most of the impacts on environment and sustainability. If necessary, identifies impacts which need mitigation	Considers some of the impacts on environment and sustainability	Minimal or no consideration of impacts on environment and sustainability

P1: Cannot be resolved without in-depth engineering knowledge at the level of one or more of K3, K4, K5, K6 or K8, which allows for a fundamentals-based, first principles analytical approach

P2: Involves wide-ranging or conflicting technical, engineering and other issues

P4: Involves infrequently encountered issues

P6: Involves diverse groups of stakeholders with widely varying needs

Rubrics for EEE400B

Table 1: Rubrics for assessment of the Design Report

Performance indicators	Outstanding (9 – 10)	Good (7 – 8)	Satisfactory (6)	Unsatisfactory (0 – 5)
DR_PI1: Develops a functional design considering applicable standards, codes of practice, health, safety, and environmental considerations. (1a) [sec-2.1] **(CO2/PO3, P2, P7)**	Appropriately partitions the problem into sub-problems, considers all relevant engineering standards and codes where applicable, involves all health, safety, and environmental issues in design	Partitions the problem into sub-problems, considers most relevant engineering standards and codes where applicable, involves major health, safety, and environmental issues in design	Partitions the problem into sub-problems to some extent, considers some relevant engineering standards and codes where applicable, involves some health, safety, and environmental issues in design	Does not usefully partition the problem into sub-problems, does not consider relevant engineering standards and codes, health, safety, and environmental issues not involved in design
DR_PI2: Formulates and evaluates alternate solutions (1b) [sec-0] **(CO1/PO2, P1, P3)**	Effectively formulates multiple solutions that functionally meet most requirements, compares and evaluates alternate solutions, extracts valid conclusions	Formulates multiple solutions that functionally meet most requirements, partially compares and evaluates alternate solutions, conclusions in line with analysis	Formulates multiple solutions that functionally meet some requirements, attempts to compare and evaluate alternate solutions, conclusions somewhat in line with analysis	Does not formulate multiple solutions, no attempt to compare and evaluate alternate solutions, conclusions not based on analysis
DR_PI3: Prepares and refines design with analysis and/or simulation of the system for implementation (1c, 1d) [sec-2.3] **(CO2/PO3, P1)**	Performs all design calculations, produces detailed design, analyzes and/or simulates to verify that the design satisfies all requirements. Design is skillfully refined to facilitate implementation.	Performs most design calculations, produces design with some details, analyzes/simulates to verify that the design satisfies most requirements. Design is refined to facilitate implementation.	Performs some design calculations, produces design with a few details, attempts to analyze/simulate the design to verify satisfaction of requirements. Design is somewhat refined to facilitate implementation.	Does not perform design calculations, detailed design not produced, analysis/simulation not done to verify satisfaction of requirements. Design is not refined to facilitate implementation.

P1: Cannot be resolved without in-depth engineering knowledge at the level of one or more of K3, K4, K5, K6 or K8, which allows for a fundamentals-based, first principles analytical approach

P2: Involves wide-ranging or conflicting technical, engineering and other issues

P3: There is no obvious solution, and abstract thinking and originality in analysis are required to formulate suitable models

P7: High level problems including many component parts or sub-problems

Rubrics for EEE400C

Table 1: Rubrics for Final report of EEE400C

Performance indicators	Outstanding (9 – 10)	Good (7 – 8)	Satisfactory (6)	Unsatisfactory (0 – 5)
FR_PI1: Discusses how the prototype of the solution is developed. [sec 3.1]	Comprehensively discusses how the prototype of the solution is developed with the help of appropriate figures, photos and diagrams	Discusses how the prototype of the solution is developed with the help of appropriate figures, photos and diagrams	Somewhat discusses how the prototype of the solution is developed with the help of appropriate figures, photos and diagrams	Poorly discusses how the prototype of the solution is developed with the help of appropriate figures, photos and diagrams
FR_PI2: Evaluates performance of the developed system as per requirements. Finalizes design based on performance evaluation (1a and 1b) [sec 0, sec 3.3] **(CO1/PO4, CO3/PO3)**	System meets all requirements or the students can identify and explain clearly when deviation from requirements occurs. Revises design with appropriate technical analysis if necessary to achieve compliance with all specification and requirements	System meets major requirements. Students can identify and explain most deviations from requirements. Revises design with technical analysis if necessary to achieve compliance with most specification and requirements	System meets some requirements. Students can identify and explain some deviations from requirements. Revises design with some technical analysis if necessary to achieve compliance with some specification and requirements	System does not meet most requirements. Students cannot identify and explain most deviations from requirements. Design not revised to achieve compliance.
FR_PI3: Finalizes design based on performance evaluation (1c) [sec 0] **(CO3/PO3)**	Revises design with appropriate technical analysis to achieve compliance with all requirements finalized in 400B	Revises design with technical analysis to achieve compliance with most requirements finalized in 400B	Revises design with some technical analysis to achieve compliance with some requirements finalized in 400B	Does not revise design with technical analysis to achieve compliance with any requirement finalized in 400B
FR_PI4: Selects and uses appropriate modern engineering tools for modeling, simulation and/or performance evaluation throughout the project (EEE400 A, B, C) [sec 3.4] **(CO2/PO5)**	Carefully selects and skillfully uses modern engineering tools knowing all the relevant limitations of the tools	Selects and uses modern engineering tools with some degree of care and skill knowing major relevant limitations of the tools	Selects and uses modern engineering tools knowing some relevant limitations of the tools	Selected and used modern engineering tools are mostly not appropriate. No knowledge of relevant limitations of the tools
FR_PI5: Achieve the milestones set in the project proposal or	All milestones are reached on time or corrective measures	Most milestones are reached on time or corrective measures	Milestones are somewhat reached on time or some	Milestones are mostly not reached on time. Corrective measures

revises the schedule appropriately to complete the project within the deadline (EEE400 A, B, C) [0] **(CO4/PO11)**	are appropriately taken to revise the schedule to complete the project within deadline	are taken to revise the schedule to complete the project within deadline	corrective measures are taken to revise the schedule to complete the project within deadline	are not taken to revise the schedule to complete the project within deadline
FR_PI6: Prepares the bill of materials and estimates the cost of the system [sec 5.1] **(CO5/PO11)**	Prepares bill of materials considering all the project components and/or parts and the cost is accurately estimated	Prepares bill of materials considering most the project components and/or parts and the cost is estimated	Prepares bill of materials considering major project components and/or parts and the cost is reasonably estimated	Prepares bill of materials ignoring important project components and/or parts and the cost is not reasonable
FR_PI7: Performs economic analysis to calculate suitable economic parameter(s) to evaluate the economic prospect of the proposed project [sec 0] **(CO5/PO11)**	Evaluates the financial prospect of the project through detailed and thorough analysis. Interpretation is clear	Evaluates the financial prospect of the project through analysis. Provides interpretation	Evaluates the financial prospect of the project through analysis.	Does not evaluate the financial prospect of the project through analysis

Table 2: Overall rubrics on report writing

Communicates the main ideas in written form [Overall] **(CO8/PO10)**	Communicates the main ideas clearly and to the point	Communicates the main ideas	Communicates the main ideas to some extent	Does not communicate the main ideas
Uses illustrations (graphs, tables, diagrams) to support ideas, analysis and interpretation [Overall] **(CO8/PO10)**	Skillfully uses illustrations to support ideas. Illustrations enhance comprehension of analysis and interpretation	Uses illustrations to support ideas. Illustrations somewhat enhance comprehension of analysis and interpretation	Uses illustrations which are related to analysis and interpretation	Either does not use illustrations or illustrations used are not relevant to ideas, analysis and interpretation
Uses citations and references [Overall] **(CO8/PO10)**	Citations and references are effectively used to duly acknowledge prior art and other people's works	Citations and references are used to acknowledge prior art and other people's works	Citations and references are used to somewhat acknowledge prior art and other people's works	Citations and references are not used or prior art and other people's works are not acknowledged
Uses a language which is mechanically (punctuation, spelling and grammar) correct [Overall] **(CO8/PO10)**	The report is free from mechanical errors	The report contains a few mechanical errors	The report contains some mechanical errors	The report contains several mechanical errors

Table 3: Rubrics for oral presentation

Performance indicators	Outstanding (9 – 10)	Good (7 – 8)	Satisfactory (6)	Unsatisfactory (0 – 5)
Communicates appropriately targeting the society at large **(CO8/PO10)**	Communication is skillfully tailored to appropriately suit the level of target audience	Communication is tailored to suit the level of target audience	Communication is somewhat tailored to suit the level of target audience	Communication is not tailored to suit the level of target audience
Focusses on the creative aspects of the solution with clarity **(CO8/PO10)**	Creative aspects are clearly articulated and emphasized. Presentation is logically and skillfully structured	Creative aspects are articulated and emphasized. Presentation structure is logical	Creative aspects are somewhat articulated and emphasized. Presentation structure is somewhat logical	Creative aspects are not articulated or emphasized. Presentation structure is not logical
Above two PIs will assess the sales pitch part of the presentation. Following PIs are for the technical part				
Designs and integrates visual aids (illustrations, demonstrations, props, etc) to support and focus presentation **(CO8/PO10)**	Visual aids are creatively designed, skillfully used and seamlessly integrated to enhance and focus presentation	Visual aids are designed, used and integrated to enhance and focus presentation	Visual aids are designed, used and integrated to enhance and focus presentation to some extent	Visual aids are not designed, used or integrated to enhance and focus presentation
Completes presentation within the allotted time **(CO8/PO10)**	Finishes the presentation as prepared within time without rushing or skipping content	Finishes the presentation as prepared within time with rushing or skipping content occasionally	Finishes the presentation as prepared within time with rushing or skipping content a few times	Does not finish the as prepared presentation within time or skips major contents to finish within time
Listens to the questions and answers appropriately **(CO8/PO10)**	Carefully listens to the questions, answers concisely transitioning skillfully between presentation and Q/A	Listens to the questions, answers to the point transitioning well between presentation and Q/A	Listens to the questions, answers somewhat to the point transitioning between presentation and Q/A in an acceptable manner	Does not listen to the questions, answers not to the point transitioning between presentation and Q/A not in an acceptable manner

REFERENCES

[1] World Health Organisation, “Cardiovascular diseases (CVDs),” Who.int, Jun. 11, 2021.

https://www.who.int/en/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)

[2] Jeon et al.: Implementation of a portable device for real-time ECG signal analysis. Biomedical Engineering Online 2014 13:160.

[3] Sayed Tanvir Alam, Md. Moin Hossain, Mohammad Dehan Rahman, Md. Kafiul Islam," Towards Development of a Low Cost and Portable ECG Monitoring System for Rural/Remote Areas of Bangladesh ", International Journal of Image, Graphics and Signal Processing(IJIGSP), Vol.10, No.5, pp. 24-32, 2018.DOI: 10.5815/ijigsp.2018.05.03

[4] Pavani, Movva & Kamarajugadda, Kishore. (2017). Design of low cost portable 12 lead wireless ECG device using TI ADS 1198. 170-174. 10.1109/IEMCON.2017.8117182.

[5] V. Choudhari, V. Dandge, N. Choudhary, and R. G. Sutar, “A portable and low-cost 12-lead ECG device for sustainable remote healthcare,” 2018 International Conference on Communication information and Computing Technology (ICCICT), Feb. 2018, doi: 10.1109/iccict.2018.8325879.

[6] M. L. Teixeira, C. Velez, D. Li, and J. Goes, “Microneedle Based ECG – Glucose Painless MEMS Sensor with Analog Front End for Portable Devices,” IFIP Advances in Information and Communication Technology, pp. 463–478, 2017, doi: 10.1007/978-3-319-56077-9_45.

[7] Y. Fu, J. Zhao, Y. Dong, and X. Wang, “Dry Electrodes for Human Bioelectrical Signal Monitoring,” Sensors, vol. 20, no. 13, p. 3651, Jun. 2020, doi: 10.3390/s20133651.

[8] T. Lili and H. Wei, "Portable ECG Monitoring System Design," 2019 3rd International Conference on Electronic Information Technology and Computer Engineering (EITCE), 2019, pp. 1370-1373, doi: 10.1109/EITCE47263.2019.9095135.]

[9]Liang Kai et al., “A system of portable ECG monitoring based on Bluetooth mobile phone,” 2011 IEEE International Symposium on IT in Medicine and Education, Dec. 2011, doi: 10.1109/itime.2011.6132113.

[10] “Norma EC-11,” calameo.com. https://en.calameo.com/read/000722933e9b7a47765ae (accessed Jan. 02, 2023).

[11] “ANSI/AAMI EC12:2000 (R2020) - Disposable ECG electrodes,” webstore.ansi.org. https://webstore.ansi.org/standards/aami/ansiaamiec122000r2020 (accessed Jan. 02, 2023).

[12] Wikipedia Contributors, “IP Code,” Wikipedia, May 23,2019 https://en.wikipedia.org/wiki/IP_Code

[13] World Health Organization, “Cardiovascular Diseases,” World Health Organization, 2022. https://www.who.int/health-topics/cardiovascular-diseases#tab=tab_1

[14] J.Hopkins. “Electrocardiogram” hopkinsmedicine. https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/electrocardiogram (accessed Jan 03, 2023).

[15] Khandpur, R. Biomedical instrumentation: Technology and applications. McGraw-Hill Prof Med/Tech, 2004.

[16] Le-Huy, P., J. P. L-Huillier, Y. Omerzouk, and E. Yvroud. "Microprocessor-based ambulatory ecg monitoring system." In Computer Applications in Medical Care, 1983. Proceedings. The Seventh Annual Symposium on, pp. 917-918. IEEE, 1983.

[17] Dr Araz Rawshani, “The ECG leads: electrodes, limb leads, chest (precordial) leads, 12-Lead ECG (EKG),” ECG learning, May 29, 2017. https://ecgwaves.com/topic/ekg-ecg-leads-electrodes-systems-limb-chest-precordial/

[18] “5-Lead ECG Interpretation, Electrocardiogram Tips for Nurses – FRESHRN.” https://www.freshrn.com/5-lead-ecg/

[19]“ECG Learning Center - An introduction to clinical electrocardiography,” ecg.utah.edu. https://ecg.utah.edu/lesson/1

[20] Bittharia, K., Tiwari, P., & Saxena, S. (2008). R–Peak Detection of ECG Signal using Thresholding Method. Irjet.net. https://www.irjet.net/archives/V6/i4/IRJET-V6I4479.pdf

[21] E. Laskowski, "What's a normal resting heart rate?," *Mayo Clinic*, Oct. 02, 2020. https://www.mayoclinic.org/healthy-lifestyle/fitness/expert-answers/heart-rate/faq-20057979

[22] "GitHub Repository'' URL: https://github.com/walidamriou/ECGGenerator/blob/master/Prototype/prototyping_by_arduino/Signal_Data_array_c/ECG_wave_c_array.txt, Accessed: May 10, 2023.

[23] "Software." https://www.arduino.cc/en/software (accessed Sep. 08, 2022).

[24] "PCB Design and Circuit Simulator Software - Proteus." https://www.labcenter.com/ (accessed Sep. 08, 2022).

[25] Coursera, "What is Python used for? A beginner's guide," *Coursera*, Sep. 22, 2021. https://www.coursera.org/articles/what-is-python-used-for-a-beginners-guide-to-using-python

[26] "ESP32 Wi-Fi & Bluetooth MCU I Espressif Systems," *www.espressif.com*. https://www.espressif.com/en/products/socs/esp32#:~:text=ESP32%20can%20perform%20as%20a

[27] "DC-DC Converters - Boost Converters (Step-Up Converter) | MPS," *www.monolithicpower.com*. https://www.monolithicpower.com/dc-dc-converters-boost-converters#:~:text=Boost%20converters%20are%20a%20type

[28] "Single-Lead, Heart Rate Monitor Front End FEATURES Fully integrated single-lead ECG front end Low supply current: 170 µA (typical) Common-mode rejection ratio: 80 dB (dc to 60 Hz) Two or three electrode configurations High signal gain (G = 100) with dc blocking capabilities 2-pole adjustable high-pass filter Accepts up to ±300 mV of half cell potential Fast restore feature improves filter settling Uncommitted op amp 3-pole adjustable low-pass filter with adjustable gain Leads off detection: ac or dc options Integrated right leg drive (RLD) amplifier Single-supply operation: 2.0 V to 3.5 V Integrated reference buffer generates virtual ground Rail-to-rail output Internal RFI filter 8 kV HBM ESD rating Shutdown pin 20-lead, 4 mm × 4 mm LFCSP and LFCSP_SS package Qualified for automotive applications Fitness and activity heart rate monitors Portable

ECG Remote health monitors Gaming peripherals Biopotential signal acquisition FUNCTIONAL BLOCK DIAGRAM LOD- LOD+.” Available: https://www.analog.com/media/en/technical-documentation/data-sheets/AD8232.pdf

[29] Josh Kohlbach, “Wholesale Price vs Retail Price: How To Calculate Wholesale Price,” May 29, 2015. [Online]. Available: https://wholesalesuiteplugin.com/wholesale-pricevsretail-price/. [Accessed: 02-Jan-2023].

[30] “Longevity Commitment | Espressif Systems,” *www.espressif.com*. https://www.espressif.com/en/products/longevity-commitment (accessed Sep. 08, 2023).

[31] “AD8232 ECG Measurement Kit,” *Cytron Technologies Malaysia*. https://my.cytron.io/c-sensor/p-ad8232-ecg-measurement-kit (accessed Sep. 08, 2023).

[32] “Bangladesh Central bank discount rate,” Indexmundi.com. [Online]. Available: https://www.indexmundi.com/bangladesh/central_bank_discount_rate.html. [Accessed: 02-Jan-2023].

[33] “Al-Arafah Islami Bank.” https://alarafahbank.com/PTD.php?fbclid=IwAR0IaZNu_qL3dkm_0JGgyFXrsUElSh mS6faM mtGGDuXH2iuxCv8NKD900zI (accessed Sep. 08, 2022).

[34] “Internal Rate of Return (IRR) | How to use the IRR Formula.” https://corporatefinanceinstitute.com/resources/knowledge/finance/internal-ratereturn-irr/ (accessed Sep. 08, 2022)

[35] https://www.mayoclinic.org/healthy-lifestyle/fitness/expert-answers/heart-rate/faq-20057979?fbclid=IwAR08-NhA_rWLtf792QkZMda5UhiNZPxTH-4K0SYW32LWhfp3O8lHPXFH7TA