Faculty of Engineering and Applied Science
ENGR 4940U Capstone Systems Design for ECSE I

Remote and Mobile Healthcare System for Home Care

R1: Project Identification, Research, and Requirements Specification

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1. Problem Identification

Over the past two years , COVID-19 has increased the burden on healthcare facilities globally not only because of its deadly nature but also because of the overwhelming number of patients[1]. With the focus being shifted on the COVID patients , non-COVID patients were delayed or denied healthcare during the pandemic either due to the limited available resources or staff[2]. Many chronically ill patients avoided hospitals during pandemic because of fear of getting in contact with the COVID- 19 virus [3]. As a result, many chronically ill patients were mostly left with two options, either risk themselves to covid or neglect their regular healthcare . In some cases patients did not even have the first option either because of the mandatory isolation or because of the hospital restrictions.

The population anxiety and isolation as a result of the pandemic eventually changed people's dietary and physical habits . This further aggravated chronic disease and psychological stress[4]. Also most of the population screening programmers including cancer screening were either deferred or neglected during pandemic which resulted in avoidable deaths [5].

While the remote healthcare system has been in use since 1960'[6], its benefits started gaining limelight during the pandemic. The remote healthcare monitoring system also known as the remote patient monitoring(RPM) is beneficial for health care during pandemics as it can provide treatment and care to patients at their home. Also , remote patient monitoring will limit the time a patient stays at hospital , hence helps in managing the healthcare limited resources[7]. Considering the COVID 19 undetermined length of stay, the use of remote monitoring healthcare systems will eventually be beneficial in upcoming days .

Beyond pandemic , remote patient monitoring reduces the risk of any disease transmission, reduces the chronically ill patients regular emergency departments visits . RPM also helps in saving the hospital stay cost. With the real time monitoring of the patient , doctors can access the patients data easily and the chances of the data accuracy increases[8]. Sometimes patients forget to convey some important information to their doctor due to several factors such as dementia . In these situations, RPM can be very beneficial as it improves the clinical insights on the condition of patients which will eventually result in providing better care to the patient[9].

2. Background and Research Review

In recent years , the use of various technologies including sensors , GPS to measure the quality of life and environment has become very prevalent . The fusion approach to connect various devices together through sensors has gained more importance recently among the other technologies[10]. The Internet of things(IOT) allows physical devices like cars , watches , kitchen appliances etc to connect . communication and share data among each other with the help of sensors and other technologies like cloud computing[11].

Remote patient monitoring is an emerging new healthcare delivery empowered by IOT which monitors the patient's real time conditions outside the hospital with the use of technology, sensors and software [12]. Remote patient monitoring targets the patients with chronic disease, mobility issues , elderly patients and patients with limited health care, for example rural people. It is better to monitor all of these patients' conditions continuously [13]. RPM uses specific technology and physical sensors to read , collect and transmit patients data to a central board like a cloud connectivity which can be accessed by the healthcare practitioners .

RPM components are similar to various modules of IOT setup. Personal Monitoring Device, Patient-side mobile application , Cloud Database and Hospital side wide Application are some major components of an RPM setup. Personal Monitoring devices are usually equipped with bluetooth modules and these are responsible for collecting relevant data from the patient all the time. These devices track all kinds of health factors, for example blood pressure , electrocardiogram(ECG) etc . These devices then further send the collected data to the patient's healthcare provider. Patient-side mobile application , another component of RPM, is a mobile app which must be compatible with the Bluetooth Low Energy (BLE) data exchange networks . This mobile app is responsible for sending patient’s data from sensors to the healthcare clinic . These apps must be user friendly and can be equipped with resources like video calling, messaging facility , booking appointments , setting medical reminders etc . The third major component of RPM is the cloud database which is responsible for holding the raw data transferred from the patient mobile and distinguishing this data into labeled, manageable clusters . Hospital side wide Application is another major component of RPM which is a web app that is responsible for displaying the collected patients data .[14]

Remote Patients monitoring system has many advantages especially in this fast growing population with increased health complications. Enhanced accessibility is one of the critical advantages of RPM as doctors will access the patient’s data quickly . Patients no longer have to miss their routine checkup , wait for long to get their doctor’s appointment and less travel cost will eventually help to cut their medical cost . Also healthcare workers will now longer have to settle with less patient data and communication with patients will become easy . Apart from this, healthcare workers now have precise and accurate data which helps them in medication management . The response time for an emergency will now be less as the healthcare workers will be able to know the cause of the problem quickly , hence can better handle the situation.[15]

Blood Pressure monitor, weight monitor , Blood glucose monitor , Spirometer, cardiac monitors, apnea monitors,audiometers,breathing frequency monitors, electroencephalographs (EEGs) , electrocardiographs (ECGs), electronic thermometers, and electronic stethoscopes are some of the remote patient monitoring devices that are available in today's market [13].

3. Design Process

The main objective that we will be accomplish is to be able to create a portable device that will have as many sensors as possible to retrieve information from the user that will store that information to the backend server of the potential web server or mobile application that has a clean and accessible UI to those who have access to it. The user will have access to basic information such as heartbeat BPM and more listed below in the stakeholder requirements, but will need to access their ECG readings from the professional that has overseen the medical records of the user.

In order to create a solution to the problem identified in the problem identification, our team must view the problem from different factors and to determine the best system that should be built, while ensuring that the device has a high degree of scalability, reliability, affordability, and adaptability and ease of access for those that require a healthcare system for Home Care.

This report will focus on the components required to achieve a functioning remote and mobile healthcare system for home care, and the proper design steps to easily manage and create the system. The proposed solution will include various sensors, different types of microcontrollers, display units, and a backend system that will act as a server to store the information that will be retrieved from the aforementioned components. This report will describe the interactions between the components and how they will achieve the goal.

Due to both the time and budget constraint and the availability of the hardware components that would be required to build the system, we will be designing a device that would allow for the hardware to wirelessly connect to a backend server to send and collect electrocardiogram signals via the sensors to be sent over a server and allow for various interactions between the hardware and software components in the overall system. This requires the utilization of a strong understanding of electronic components and software adequacy and will require the usage of understanding how embedded boards can be capable of running a server to retrieve and store data over a network, and how the low level components such as the display unit and the sensor will be used for the end user.

To design this system, the approach that we will need to take for the design process is an iterative process with our group finding multiple test subjects and testing to refine our model as required. To add on, our design methodology will include the identification of the individual components and subsystems and how they will be incorporated in the design as a whole. In doing so, we will be supplementing a thorough identification of the required interfaces, a high standard of documentation to understand how the data is being sent over the various data transferring capabilities, and the degree of abstraction to understand each layer of the system architecture.

Four our design process, we will partake in an agile approach to the project. Because of the scalability and flexibility during the agile process, we will be able to successfully complete our tasks with the provided architecture below, as well as be able to make predictions based on how much time it will take to implement a certain feature. The agile process will also have a high level of reliability as it will have the ability to fit all the needs that will be required upon us.

The aforementioned iterative approach will explain the development of the model and the design process, which in turn will indicate that we will need to constantly test while making adjustments as they are needed during the development process. During this time, ensuring each subsystem is working at the top level of functionality as per the specs before the data is able to be sent to the server to hold the patient information. This in turn will allow the project to progress without any issues and delays.

The design process will begin with understanding and the identification of the multiple components and interactions of the components in the subsystem. In the tables below, we have identified two separate projects to propose as preliminary designs (Table 3-1), (Table 3-2).

Table 3-1 Component Design 1

Component Name	Description
Server Unit (Raspberry Pi Model B)	The Raspberry Pi Model B will be the Server computer that will be the brain of the system. It will be connected to the entire system via the provided GPIO pins. It will be accessible as a User Interface (UI) server system that will have sensors connected to it via the GPIO pins and using a MQTT process will provide information receiving the patient's electrocargiongram signals and the end user's heartbeat. It is also responsible to store the patients information that can be later accessed by the administrator and to the health care professionals that

	can override the administrator commands to view the stored data.
Display Unit	The display unit is responsible for showing that the device is functioning and will display the time and battery life to the end user.
ECG Unit (Polar H10 (Heart rate sensor))	The heart rate monitor will act as a way to monitor and to receive the information from the end user, by accessing the Raspberry Pi's GPIO pins. It will keep track of the heart rate fluctuation.
End User Unit (BPM Reader)	The user will be able to access their BPM
Monitoring System Unit	The Monitoring System Unit will be where all the information and the server will have all its main access to. It will be connected to every component in the system. It will be responsible to store all the end user information as required by the individual.
PPG Unit (Pulse Sensor + MCP3008 ADC IC)	The PPG unit will retrieve the data from the pulse sensor and pass it along to the MCP3008 via an analog signal and then will be able to transfer that information of the ECG to the number of Hz that is being transmitted.
Oximeter Unit (Masimo RAD-8 Oximeter)	The oximeter unit will be able to monitor oxygen level and heart rate that will have its information stored and assessed by the healthcare professional to check for any abnormalities in the reading that gets stored into the back end server.

Table 3-2 Component Design 2

Component Name	**Description**
Server Unit (Arduino Mega)	The Arduino will act as a high powered computer that will be able to connect to the server via SSH protocol and send the data retrieved from the device to the cloud server. It will be accessible via a User Interface (UI) server system that will have the cloud script be running within the Arduino IDE to send information from the device to the allocated cloud server receiving the users ECG reading, PPG, BPM, and blood oxygen readings. It will also be responsible for withholding the user information that can later be accessed by a healthcare professional that will have administrator rights to the system to view the stored data.

Display Unit	The display unit is responsible for showing that the device is functioning and will display the time and battery life to the end user.
ECG Unit (ECG Module AD8232)	The ECG module will act as a way to access the ECG requirements as deemed necessary by the user to retrieve the information from the device and then send that information over to the cloud server, disallowing the user to have direct access to the readings.
End User Unit (BPM Reader)	The user will be able to access their BPM
Monitoring System Unit	The Monitoring System Unit will be where all the information and the server will have all its main access to. It will be connected to every component in the system. It will be responsible to store all the end user information as required by the individual.
Photo Sensor (Photodiode LPT80A)	The Photo Sensor will allow for the display unit to interact with the user's PPG reading via a waveform pattern that will be displayed moving through an average filter.
Pulse Detector Unit (Pulse Oximeter MAX30102)	The Pulse Detector Unit will provide a high sensitivity pulse oximeter that the patient will be able to receive and acknowledge alongside a hate rate sensor.
Math Unit	The Math Unit will calculate the ECG waveform to calculate the Hz of the ECG waveform.

The software design process involves being able to identify and develop the software architecture in cohesion with the hardware design using the components required for the prototype. Below in **Figure 3-2,** a multi layered architecture diagram is being proposed as the main system architecture.

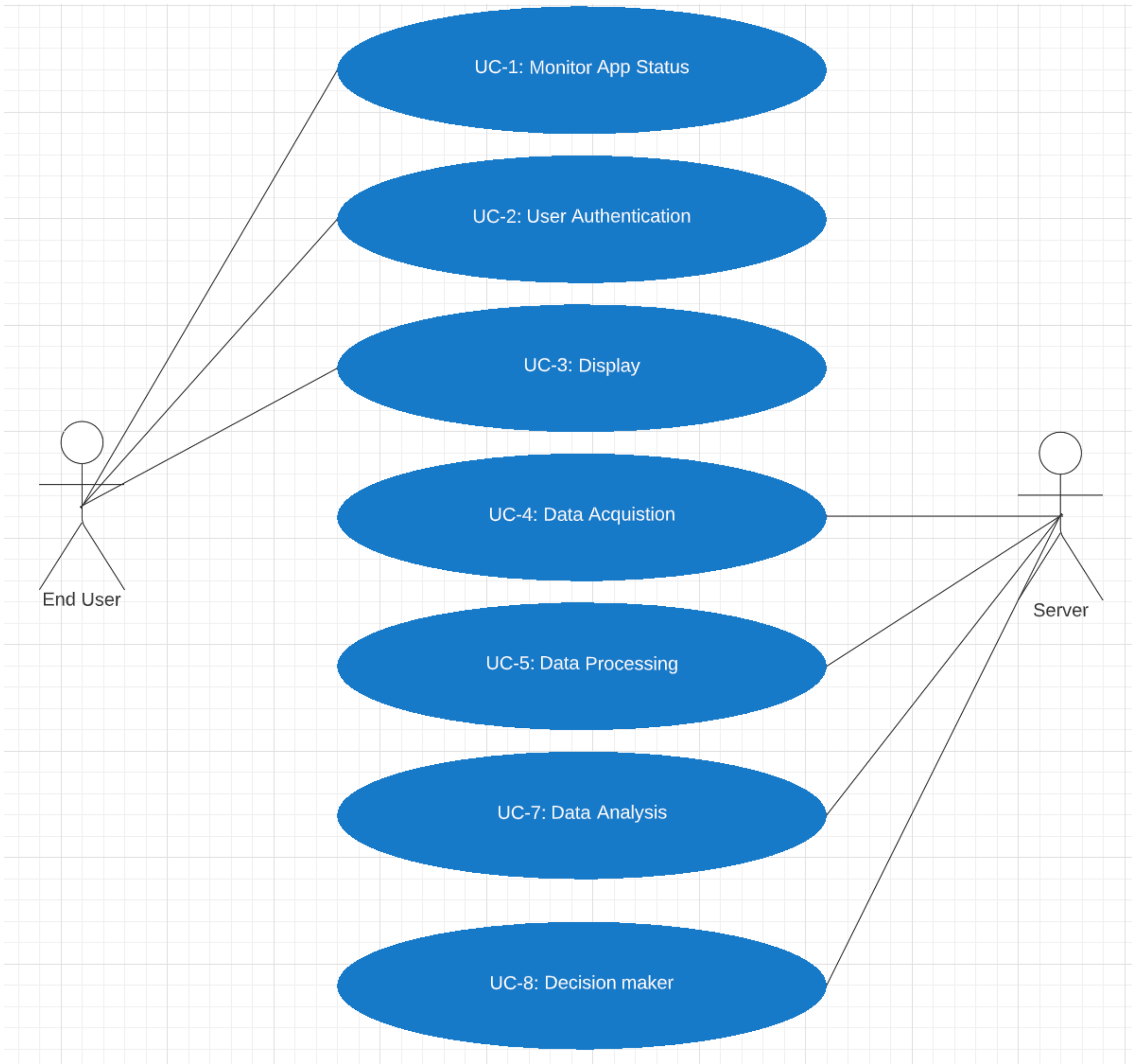

Figure 3-1 Software architecture in cohesion with the hardware for the Mobile and Remote HealthCare monitoring system

The progress of the project will be tracked in accordance with the following:

1. Each members' individual weekly activity report
2. Consistent testing and evaluating of our prototype in accordance with the milestones set with our group found in Table 7-1 below.
3. Weekly project progress meeting with faculty advisor Dr. Mikael Eklund
4. Weekly project progress reports with the team members.

With the constant prototyping and monitoring of our project by the team as well as the faculty advisor alongside the activity logs of each student and the project reports, this will ensure an appropriate outcome for the stakeholders for the project. THe team is responsible for coming to a unanimous decision when it comes to any measures throughout the progress of the project. Furthermore, each individual of the team will also be responsible for each of the given tasks that they are responsible for, that being but not limited to: development of the server, handling the electronics, integration of the server to the website.

4. User Stories/Scenarios:

4.1.1 Scenario One: Pulse Detection

User has come back after a long marathon run and notices themselves breathing faster and heavier. User presses the buttons on the device to check his heart rate after a burst of intense activity. The device displays the user's heart rate.

4.1.2 Scenario Two: Continuously Monitor your Heart Rate

User is facing irregular heartbeat patterns and is feeling a noticeable deterioration in health, the device detects the irregularity and gives them a notification notifying them of unusual/irregular heart rate trends informs them to see a doctor as soon as possible.

4.1.3 Scenario Three: Data Storage to Cloud

User visits their doctor for a regular check-up. Whilst the user was using the device, the data and recorded averages are being stored and saved on a cloud server. Health care professionals can access this information when required to determine fluctuations and pinpoint when irregularities/problems began to form, allowing them to get to the root cause quicker and diagnose problems faster.

4.1.4 Scenario Four: Internet/BT compatibility with Cell-Phone/Computer

User wants more in depth analysis of the recorded data which is not accessible from the medical monitoring system's interface. To do this the user is required to use an external device such as a cell phone or a computer.

4.1.5 Scenario Five: Data Storage to Cloud

Enduser has started living a healthier lifestyle in the past year, they are eating clean, working out daily and have quit smoking. To track their progress and make sure it is improving their cardiovascular system the user wants to compare their prior resting heart rate/ active heart rates with their new found heart rates. The user will need their health professional to retrieve their older data and compare their progress with the new ones. This information is not directly accessible to the user to prevent anxiety and stress from self-diagnosis.

4.2 Use Cases

Below are the use cases that will be considered for during the design process of the Medical Monitoring System (MMS). The intended design of the system, system goals, major features and system complexity will all be addressed in this section.

Table 4-1 – Heart Rate Check on Medical Monitoring System

Use Case ID	UC-MMS-HRC-1
Use Case	User wants to check their current Heart Rate
Description	User presses a button on the System's Interface which will then take the user to a screen where there heart rate is displayed in Beats per minute.
Actors	1. User 2. Heart Rate Sensor 3. MMS Display 4. Database System
Pre-Condition	System must be turned on and running.
Post-Condition	After the Heart Rate is requested, the display will show the Heart Rate BPM and allow the user to go back to the home page.

Use Case Component	Step	Steps
Heart Rate Sensor	1	Heart Rate is continuously being measured when on (if applicable, averages are recorded, minutely/hourly)
MMS Display	2	Button is clicked to request the Heart Rate to be shown on screen.
MMS Display	3	Fetch the current heart rate and print it on the Display.
MMS Display	4	Allow user to either re-attempt the testing or let

		the System go back in to resting mode.
Extensions		
Heart Rate not Detected	1a	Notify user via user interface to try again as sensor did not detect a BMP.

Table 4-2 – Heart Rate Irregular trend e-mail.

Use Case ID	UC-MMS-HRI-2
Use Case	Doctor is notified of the patients health status.
Description	User’s heart rate has become too fast or too slow which than their regular historical data. This is detected by the system and an email will be sent to the user’s doctor.
Actors	1. User (Doctor) 2. User (Patient) 3. Database System
Pre-Condition	System must be turned on and doctor’s email is already saved.
Post-Condition	-

Use Case Component	Step	Steps
Heart Rate Sensor	1	Heart Rate is continuously being measured when on (if applicable, averages are recorded, minutely/hourly)
MMS Display	2	Irregularity detected in the program.
Server	3	Sends an email to the Doctor.
Extensions		
Faulty Readings recorded, I.e lose connection with skin and shows a terrible inaccurate result.	1a	Backend algorithm has a certain threshold and criteria where results are discarded from the Databases. For example, during high intensity training the system recorded 5 BMP for a minute in between minutes showing 100 BPM. Clearly the 5BMP minute in that scenario is an error and should not be accounted.
Email to the Doctor failed.	1b	Send an email to the user that communications with the doctor is compromised and to

		input a correct email address into the system.

Table 4-3 – Internet Connectivity with Mobile Application using WIFI

Use Case ID	UC-MMS-ICM3
Use Case	IoT compatibility, system has to have ability to communicate with other devices
Description	User's wants to check the analysis done by the mobile application. The data that has been recorded by the MMS is stored and analyzed on the Mobile app.
Actors	1.User 2. Mobile Application Interface 3. Database System 4. Hosting Server
Pre-Condition	Device has to be turned on as well as the mobile application. Server has to be running and routing messages from the MMS to the Mobile Application.
Post-Condition	-

Use Case Component	Step	Steps
Heart Rate Sensor	1	Heart rate sensor records data.
Heart Rate Sensor Server Mobile App	2	Recorded data that was detected from the Sensor is routed to the Mobile application where the data is processed.
Mobile Application Interface	3	The Processed data is then displayed in a manner that is understandable to the user.
Extensions:		
Server fails	1a	The data from the Medical Monitoring System Cannot be communicated to the Mobile app due to failure on the server cause message routing problems. Returns error on the App UI.

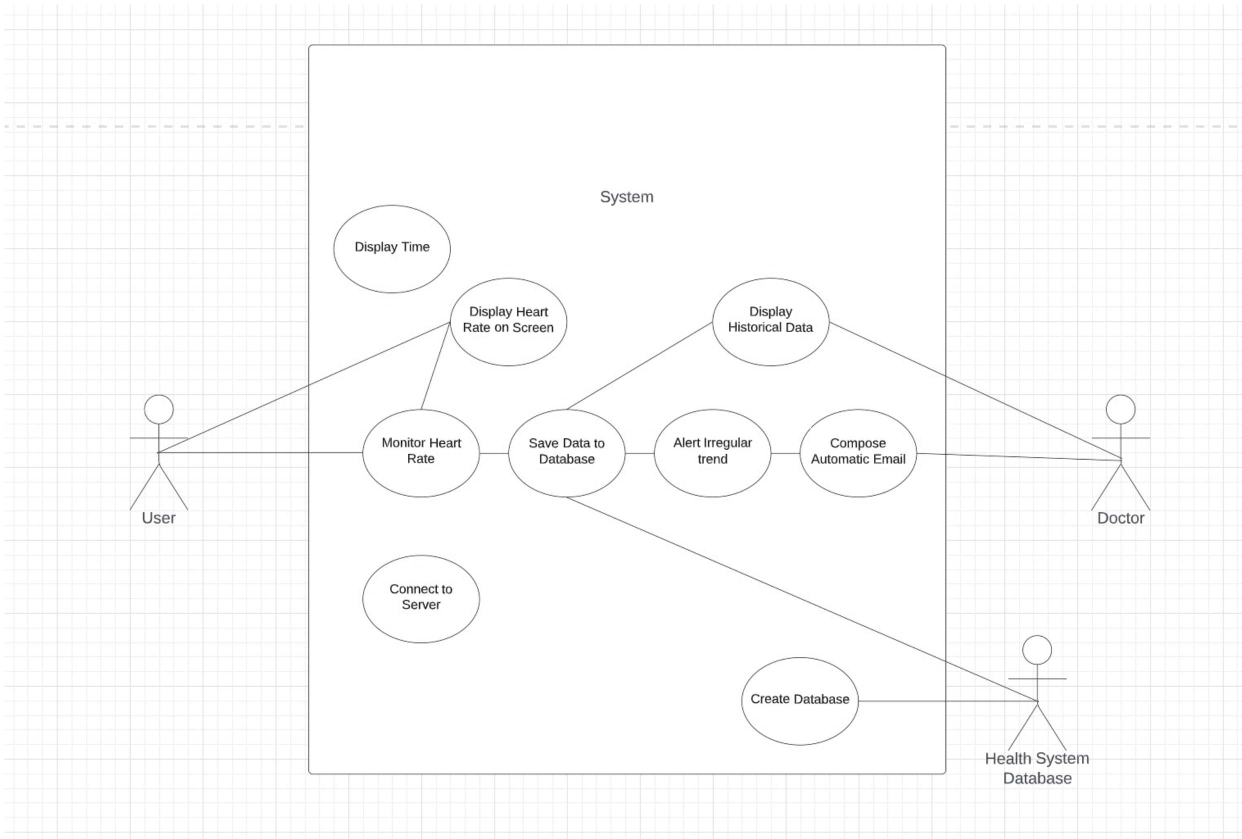

Figure 4-1 UML Chart of Use Case Scenarios

5. Stakeholder Requirements and Traceability Matrix

5.1 Stakeholder Requirements

Table 5-1 Stakeholder Requirements

Table 5-1 below includes all the stakeholder requirements that have been identified. These requirements will be traced throughout the duration of the project until completion.

Requirement ID	Requirement Description
[REQ-DIAG-1]	The mobile medical monitoring system must be able to perform diagnostics and collect

	data for measures like electrocardiogram (ECG), heart rate (in BPM), photoplethysmography (PPG), blood oxygen levels and calculating the frequency of the ECG (Hz) from users.
[REQ-STOR-1]	The application must be able to store the data from the checkups and provide a real-time analysis of the data accumulated.
[REQ-DISP-1]	The heart rate monitor system must display the results of a checkup within moments.
[REQ-DISP-2]	If any of the monitors detect any abnormalities with the user, it should notify the user immediately and advise them to visit a physician or depending on the severity of the situation to inform the user to contact emergency services.
[REQ-DISP-3]	If the audiometer detects a high decibel (dB) level, it should notify the user that the level of noise could damage their hearing.
[REQ-DATA-1]	While the data is being collected, the system should filter out any bad noise that may result in inaccurate data, such as when performing an ECG.
[REQ-DATA-2]	The user should not be able to see all the data collected from the diagnostics. Some data should only be seen by physicians.
Optional Requirement [REQ-DISP-3]	The information displayed should be in an understandable user interface that untrained users can comprehend.
Optional Requirement [REQ-STOR-2]	The collected information can be sent to a third-party for analysis, with the user's permission.
Optional Requirement [REQ-DES-1]	The device is designed to be used by a single user.

5.2. Traceability Matrix

The traceability matrix, Table 5-2, was created. It includes the requirement ID, the use case ID and acceptance ID(s) associated with that.

Table 5-2 Traceability Matrix

Requirement ID	Use Case ID	Acceptance ID
[REQ-DIAG-1]	[UC-MMS-HRC-1]	[AT-DIAG-1] [REQ-DISP-1] [AT-DET-1]
[REQ-DISP-2]	[UC-MMS-HRI-2]	[AT-ALM-1]
[REQ-STOR-1]	[UC-MMS-ICM3]	[AT-STOR-1]

6. Definition of Acceptance Tests

The acceptance test table, Table 6-1, identifies all the acceptance tests.

Table 6-1 Acceptance Tests

Acceptance Test ID	Description
[AT-DET-1]	System detects if a user is wearing the device.
[AT-DIAG-1]	System performs diagnostics on request by the user.
[AT-DISP-1]	System displays the information/results of the diagnostics after it has been performed.
[AT-ALM-1]	System alerts the user if there are any abnormalities or issues with the results of the diagnostics and informs the user to seek medical assistance.
[AT-STOR-1]	System stores the collected data and sends it

	to a cloud-based system.
[AT-STOR-2]	System stores the data for users to review afterwards on the mobile app. (For example: the data collected within the past six months)

7. Project Plan

7.1 Project Milestones

The table below represents the project milestones and anticipated start and end dates (**Table 7-1).**

Task Number	Task	Start Date (MM/DD/YYYY)	End Date (MM/DD/YYYY)
1	**Idea Research**	**09/18/2022**	**09/22/2022**
2	**Project Research**	**09/23/2022**	**10/02/2022**
3	**Design Identification**	**10/06/2022**	**10/10/2022**
4	**Capstone Report 1 Deliverable**	**10/09/2022**	**10/16/2022**
5	**Hardware acquisition**	**10/26/2022**	**11/02/2022**
6	**Hardware compilation and Prototyping**	**11/04/2022**	**11/10/2022**
7	**Software Component design and development**	**11/03/2022**	**11/07/2022**
8	**Capstone Report 2 Deliverable**	**11/02/2022**	**11/08/2022**
9	**Software Integration with Hardware**	**11/12/2022**	**11/19/2022**
10	**Integration Testing**	**11/19/2022**	**11/21/2022**
11	**Acceptance Testing**	**11/22/2022**	**11/29/2022**
12	**Project Demo**	**12/01/2022**	**12/02/2022**
13	**Project Poster**	**12/01/2022**	**12/02/2022**

14	**Final Engineering Report**	**11/25/2022**	**12/06/2022**
15	**Team Retrospective Report**	**12/01/2022**	**12/07/2022**
16	**Individual Activity Long**	**11/03/2022**	**12/12/2022**

7.2 Project Gantt Chart

Figure 7-1 describes the project Gantt Chart for the project's projected timeline.

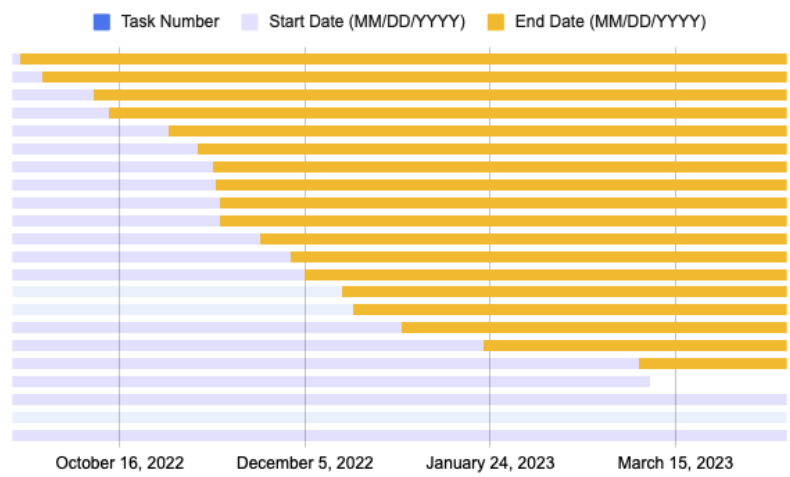

Figure 7-1 Project Gantt Chart

8. Contribution Matrix

The list of tasks and contributions for this report are indicated in Table 8-1 below.

	Team Member	Team Member	Team Member	Team Member
Task	Mamun Hossain	Aaditya Rajput	Gobikah Balaruban	Manreet Kaur
Project Research	25%	25%	25%	25%
Background Research	20%	20%	20%	40%
Design Process	70%	10%	10%	10%
Scenarios	10%	60%	10%	20%
Use-case generation	10%	50%	15%	25%
Stakeholder Review	15%	15%	60%	10%
Acceptance Tests	20%	10%	50%	20%
Project Plan	30%	10%	10%	50%
Contribution Matrix	25%	25%	25%	25%

Table 8-1 Contribution Matrix

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