System Design for Mechatronics Engineering

Back
End
Developers

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April 4, 2023

1 Revision History

Date	Version	Notes
2023-01-18	1.0	Initial documentation
2023-03-15	2.0	Modified and proofread for Revision 1
2023-03-25	2.1	Incorporated TA feedback
2023-04-04	2.2	Added logo and style to the document

2 Reference Material

This section records information for easy reference.

2.1 Abbreviations and Acronyms

Refer to SRS for a comprehensive list of abbreviations and acronyms.

symbol	**description**
Lipo battery	Lithium polymer battery
PCB	Printed circuit board
TFT LCD Display	Thin film transistor liquid crystal display
FSM	Finite state machine
UI	User interface
CAD	Computer aided design for 3D models
SPI	Serial peripheral interface

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3 Introduction

This document provides a detailed description of the system design for the EMAnator; the system currently under development by the Back End Developers which aims to assist researchers in performing Ecological Momentary Assessment for older adults. The goal of this design is to construct a system which fulfills all the requirements specified in the System Requirements Specification, and that meets the needs of EMA researchers.

This document provides the big-picture goals of the system, an overview of the project, a comprehensive list of system variables, and details regarding the user interfaces of the system. It also lists the various hardware and electrical components involved in the design of the system. Finally, it includes a high-level timeline for the development of the system.

The design presented in this document is the result of collaboration between the Dr. Luciana Macedo of the School of Rehabilitative Sciences and the Back End Developers development team. We have discussed the project requirements and identified the best approach to meet them. This is covered in detail in the document titled Problem Statement and Goals.

The Back End Developers hope this document serves as a useful guide for anyone involved in the development or deployment of the system.

4 Purpose

In general, engineering design documentation is a set of documents that outline the detailed specifications for an engineering project. It describes the design of the project, including its requirements, the materials to be used, the processes involved, the safety and environmental considerations, and the estimated costs. The purpose of engineering design documentation is to provide a comprehensive record of the project that can be consulted by engineers, oversight bodies, and other stakeholders throughout the project's life cycle.

This documentation includes technical drawings, process diagrams, system and component specifications, and relevant schematics and images. It also provides a basis for quality control and assurance, as well as a way to track progress and identify potential areas of improvement. It is an essential part of any engineering project, as it ensures that all stakeholders have a clear understanding of the project and the necessary steps for its successful completion.

This project currently has the current pieces of design documentation available:

- Problem Statment and Goals
- Development Plan
- System Requirements Specification
- Hazard Analysis
- VnV Plan
- Module Guide
- Module Interface Specification

5 Scope

This system in theory is very simple. An array of sensors grabs info regarding the position, speed, orientation, etc. and uses that information to understand the current state of the user. This data is then used to generate prompts that the user will answer and all the collected data is compiled, processed and stored within the system. Finally, researchers will analyze the collected data and generate observations.

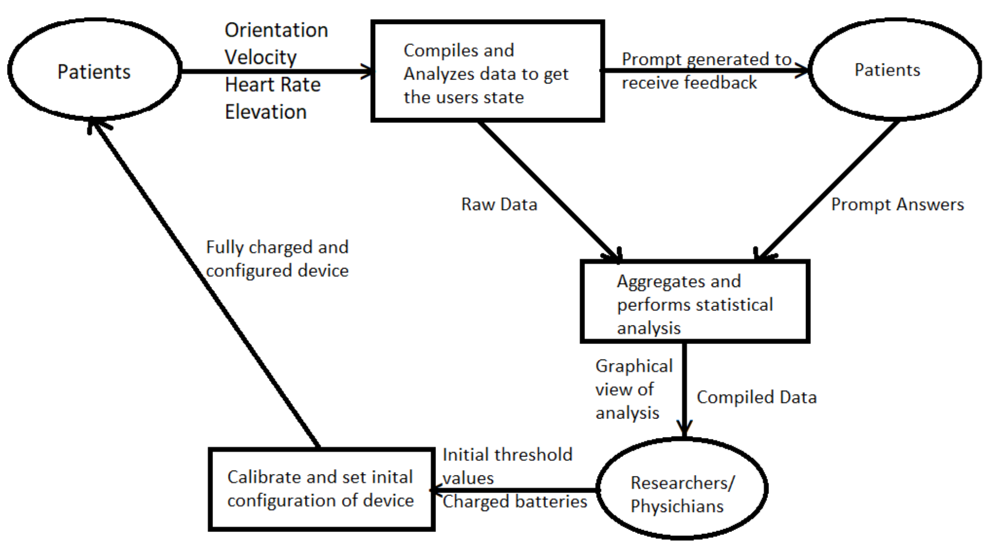

Figure 1: System Context

6 Project Overview

6.1 Normal Behaviour

Refer to SRS Section 12.

6.2 Undesired Event Handling

Refer to SRS Section 13.

6.3 Component Diagram

Refer to Section 10

6.4 Connection Between Requirements and Design

Requirement	**Deisgn Decisions**
R1	The user will be reminded to charge the device during their introduction to the device and a LiPo for longer battery life.
R2	The device integrates the heartrate sensor and the MPU accelerometer on the same PCB. Using them together in a sensor array module minor movements of the user can be tracked and then stored in the database.
R3	Using the same sensor integration above the user is prompted based on researcher defined thresholds on initial device setup which is done in the local GUI.
R4	The device is in the form of a smartwatch. It is lightweight and intuitive for the user.
R5	In the local user interface, the researcher is able to configure thresholds for the input parameters that can be customized for each user.
R6	Using the SD card reader module data is stored when a user completes the EMA which is prompted on the watch display.
R7	Using the device manager module and the SD card module data can be extracted and read locally by the researcher. Once read using the grapical plotter module the data can be analyzed in graphical format or extracted in raw format through an encrypted *.csv file.

Table 1: Components of Hardware UI

7 System Variables

7.1 Monitored Variables

Refer to SRS Section 5.1.2.

7.2 Controlled Variables

Refer to SRS Section 5.1.3.

7.3 Constants Variables

Refer to SRS Section 1.4.

8 User Interfaces

8.1 Hardware User Interface

The device is worn by a participant on the wrist for measuring activity and generating prompts. The following items will be shown on the display of the activity tracker:

Description	Behaviour of TFT Display
Power up of activity tracker.	Displays Back End Developers on startup.
Default behaviour, no activity tracked.	Displays date and time.
Activity tracked.	Prompt generated on screen, for example: Are you in pain?
Answering prompts using touch sensor (bezel).	Toggle between different options on screen. For example: (Yes/No).

Table 2: Components of Hardware UI

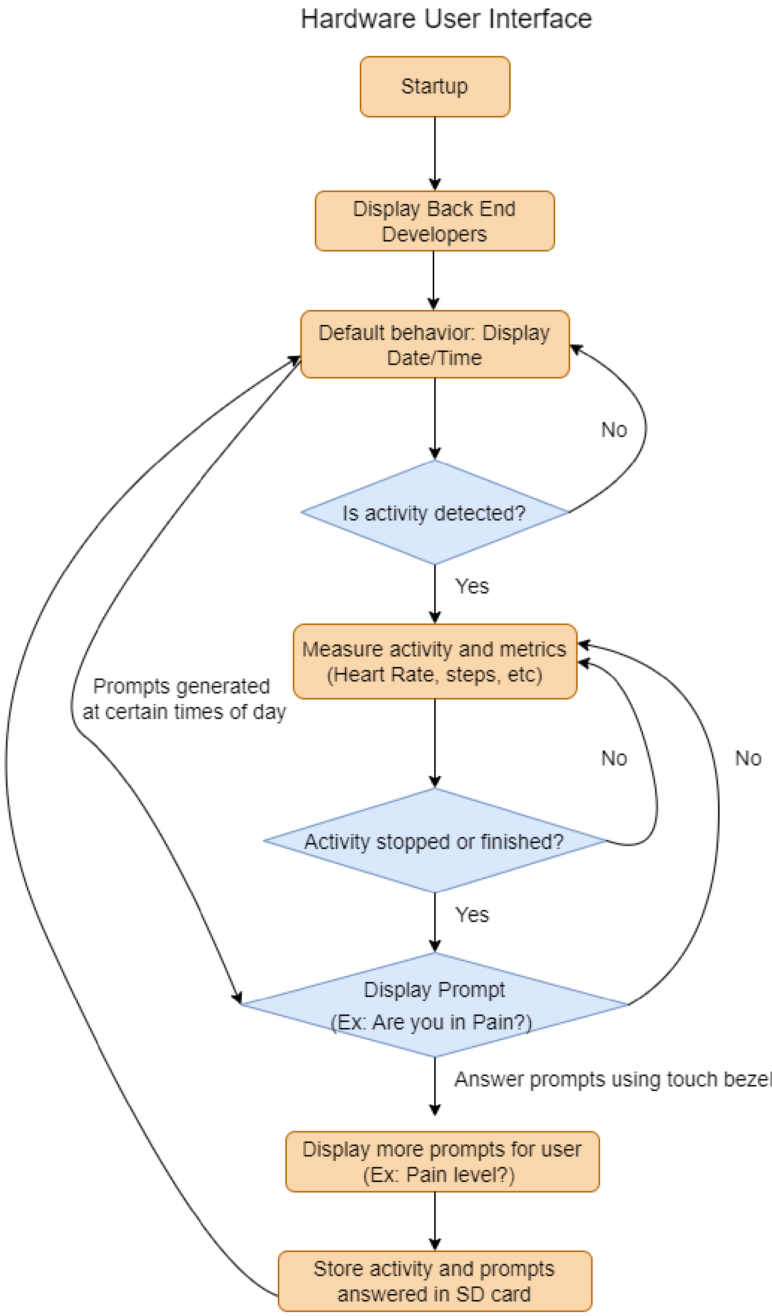

Figure 2: FSM for Hardware UI

Figure 3: Display on activity tracker at startup

Figure 4: Display of date and time on activity tracker.

8.2 Software User Interface

The software user interface will be used by the researcher for configuring the activity tracker. The interface will be on the host computer and will be able to store participant data, create new data and view records using encryption. The interface will also have authentication, and only the researcher will be able to log in. The following features are available on the software user interface:

Options on UI	**Description**
Main window	Main menu that leads to different windows when clicked.
Connect to tracker	Connects to SD card for device and shows status of connection.
Create records window	Creates new record for particpant and stores it in a database. A record can only be created if the correct username and password are provided.
Records window	Participant records can be viewed in a tabular format and can be searched/filtered.
Data view window	Data stored on SD card can be viewed and filtered. Data can also be plotted using the graph button. For example: Heart rate vs time.

Table 3: Components of Software UI

Below is an example of the Software User Interface for the Main window.

Figure 5: Main Window for Software UI

For more examples of the Software User Unterface, refer to Appendix A.

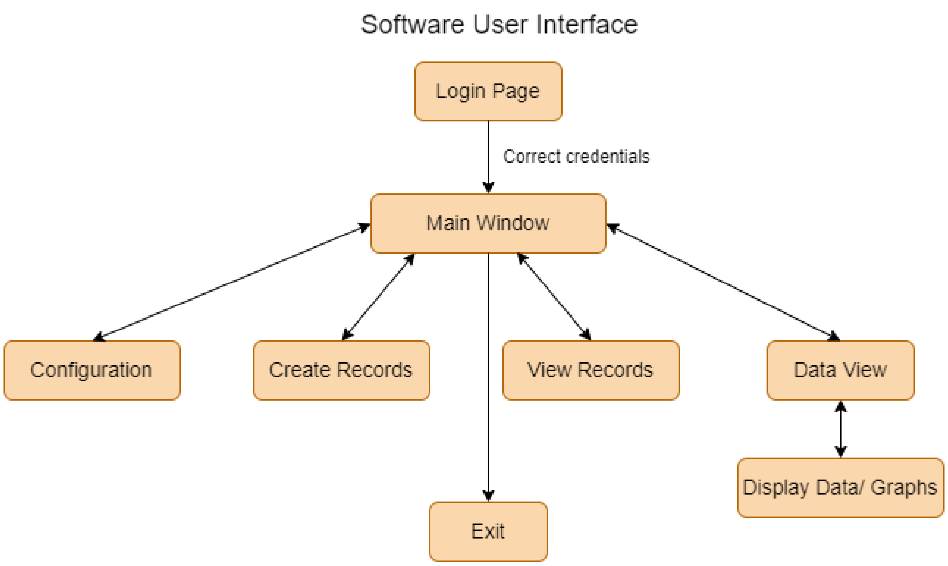

Figure 6: FSM for Software UI

9 Design of Hardware

The touch bezels shown in figures 7, 8, and 9 will be used as a bezel to navigate options on the activity tracker. The wires connected to each segment send a corresponding signal which can be used to navigate options and select a response.

Figure 7: TFT Display with Custom 3D Printed Case

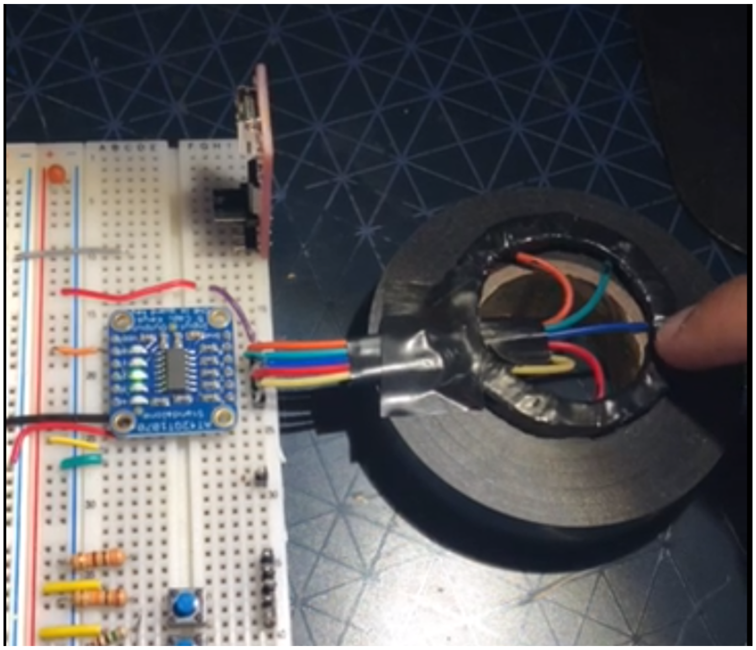

Figure 8: Circuit of Custom Built Reactive Touch Sensor

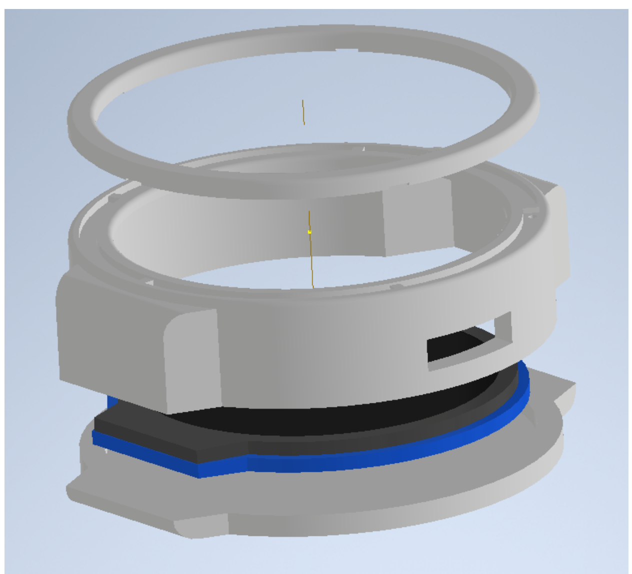

Figure 9: CAD Assembly of Touch Bezel, Display Case and TFT Display

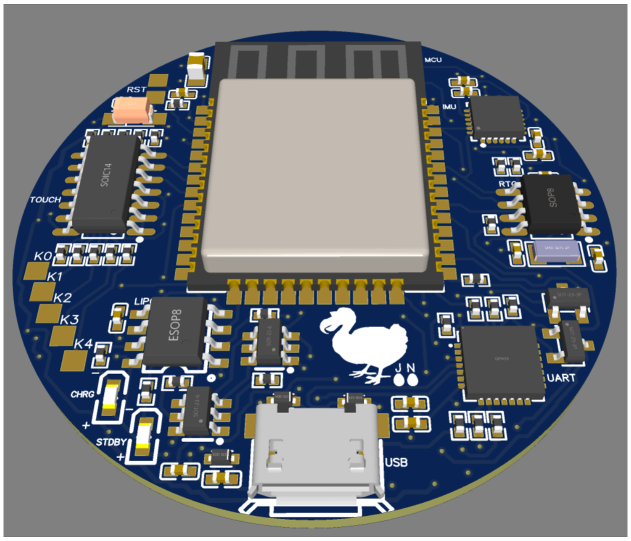

Figure 10: Top view of Custom PCB

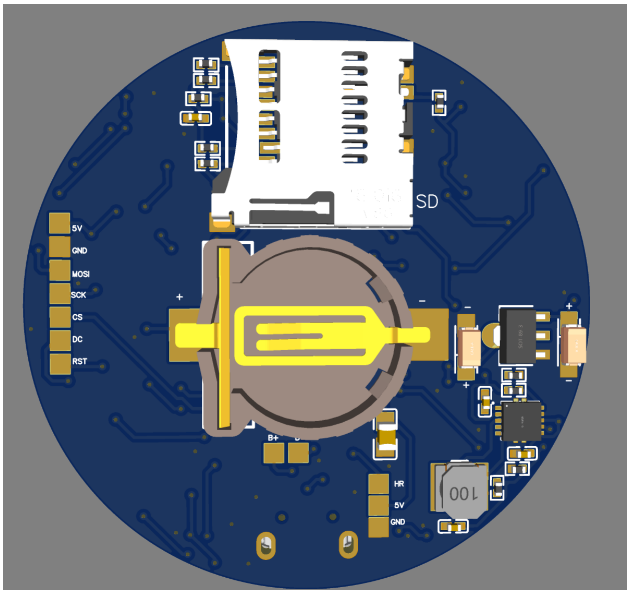

Figure 11: Bottom view of Custom PCB

Refer to Appendix B for individual CAD designs.

The following list of items will be custom designed and fabricated:

- Custom PCB designed using Easy EDA and fabricated using JLCPCB
- 3D printed casing for TFT display/activity tracker.
- Touch sensor (bezel) to navigate through activity tracker.

Refer to table 6 in Appendix for detailed information on high-level hardware components used.

10 Design of Electrical Components

The schematic/circuit diagrams shown below are used to generate the PCB layout. It consists of the following modules:

- ESP32-WROOM microcontroller
- Touch sensor
- Voltage regulator circuit
- Battery protection circuit
- RTC
- MPU 6050 accelerometer
- MicroSD card
- LiPo battery
- Pulse Sensor heartrate

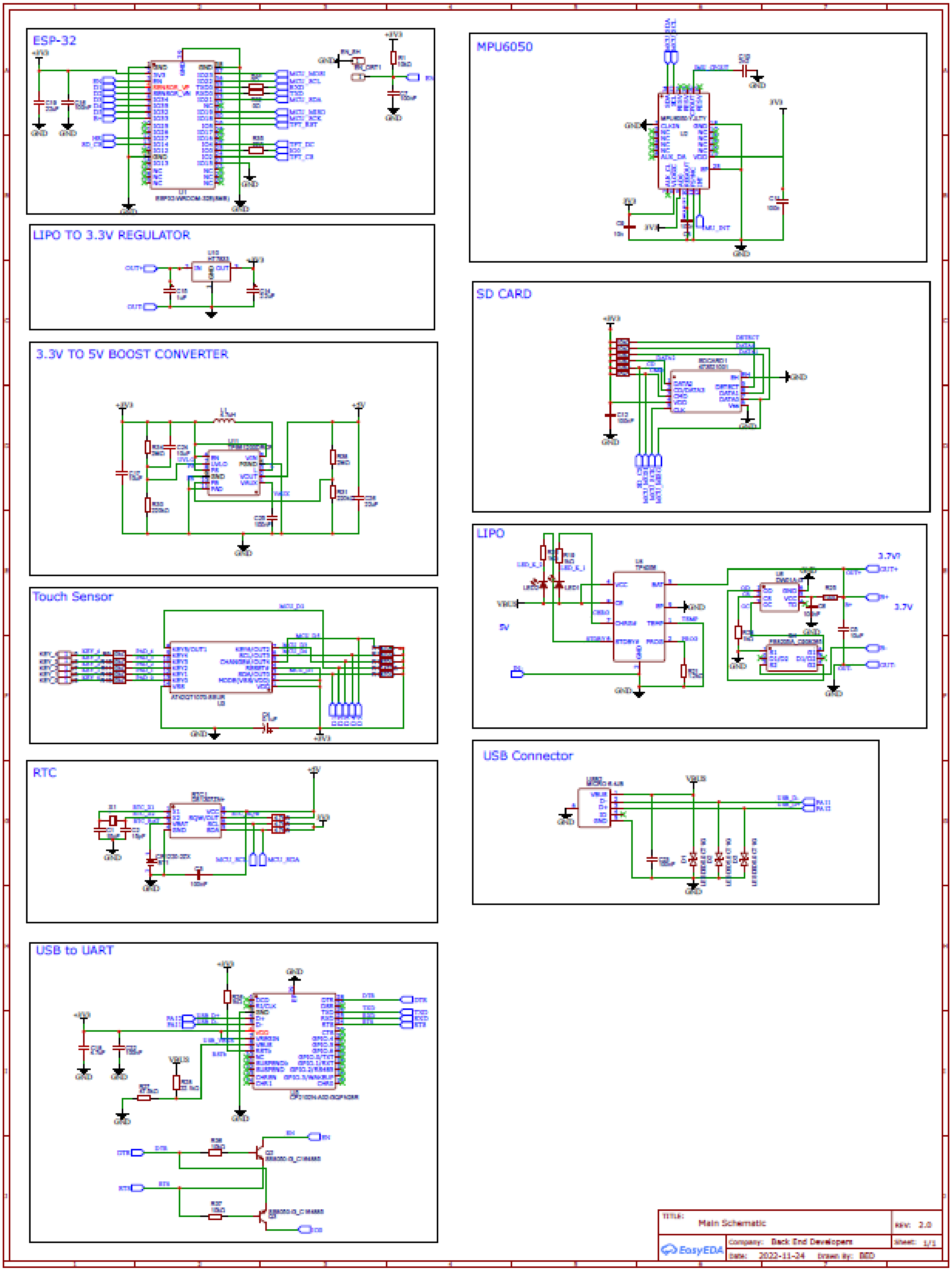

Figure 12: Schematic for PCB

The custom designed PCB is shown in figure 13.

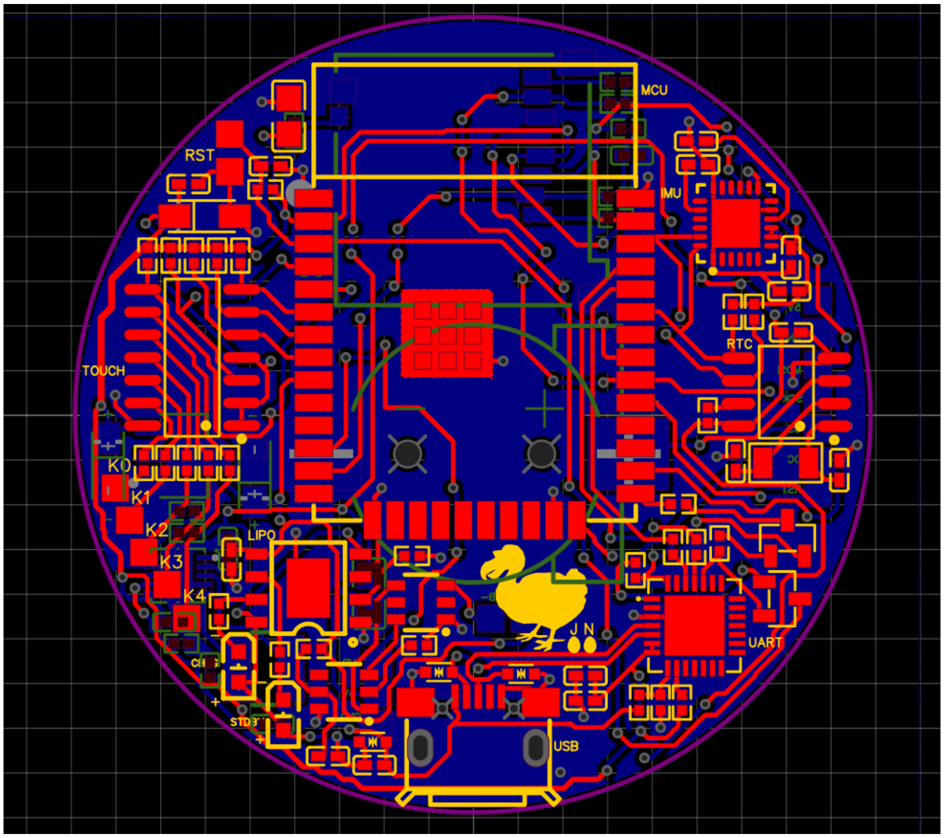

Figure 13: Layout of PCB design

Refer to table 7 in Appendix for detailed information on electrical components (module-wise) used in the PCB design.

11 Design of Communication Protocols

There are two standard communication protocols that are used in the project, I2C and SPI. The following modules use I2C communication protocol:

- Code for RTC using I2C communication.
- TFT display driver.
- MPU 6050 driver.

The IO expander module uses SPI communication protocol.

12 Timeline

The following table outlines the project timeline for revision 0 demonstration:

Table 4: Timeline of project Pt. 1

Timeline	Project Task	Member	Responsibilities
Dec 2022 - Jan 2023	Front end software UI and functionality	Labeeb Zaker	Designing user friendly UI implementation. All UI design should be completed by the end of January.
Dec 2022 - Jan 2023	Back end software UI and functionality	Jessica Bae	Implement authentication and encryption functionalities. Both funtionalities should be completed and cause no error.
Jan 2023	Database management	Nish Shah	Implement database with software UI to read, store and write data. The UI should be able to fully interact with the database based on its implemented buttons.
Jan 2023	UI and device connection	Nish Shah	Implement bluetooth connection and microSD connection between UI and device. MicroSD functionality should be completed. However, bluetooth functionality can be done after revision 0.
Dec 2022 - Jan 2023	Accelerometer PCB schematic design	Anish Rangarajan	Implement schematics for accelerometer and gyroscope module in PCB. Schematic should be complete for PCB manufacturing.
Dec 2022 - Jan 2023	microSD PCB schematic design	Jessica Bae	Implement the circuitry for microSD module in PCB. Schematic should be complete for PCB manufacturing.
Dec 2022 - Jan 2023	LiPo battery PCB schematic design	Jonathan Hai	Implement the circuitry of LiPo battery module for PCB. Schematic should be complete for PCB manufacturing.

Table 5: Timeline of project Pt.2

Timeline	Project Task	Member	Responsibilities
Dec 2022 - Jan 2023	PCB layout design	Anish Rangarajan	Implement PCB layout with proper routing. The layout should be complete for PCB manufacturing.
Nov 2022	Display driver	Labeeb Zaker	Display driver for the device should be able to handle displaying time and prompt, as required per revision 0.
Nov 2022	Device frame CAD model	Anish Rangarajan	CAD models for device frame.
February 1 2023 - Feb 6 2023	Integration of all sensor modules	Jonathan Hai, Oliver Foote	Integrate all sensors and systems and create test benches to check correct functionality.
Jan 2023 -March 2023	PCB testing	Jessica Bae, Oliver Foote	Performing system-wide testing on PCB based on VnV-Plan
Continuous untill April 2023	Documentation	All team members	Complete all documentation.

A Software Interface

Figure 14: Record Window

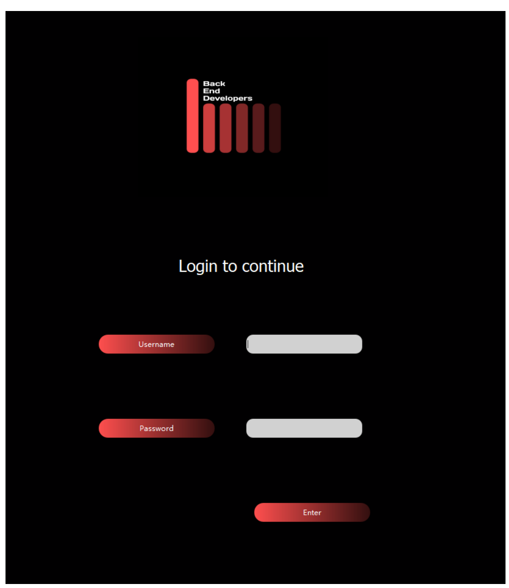

Figure 15: Login Page

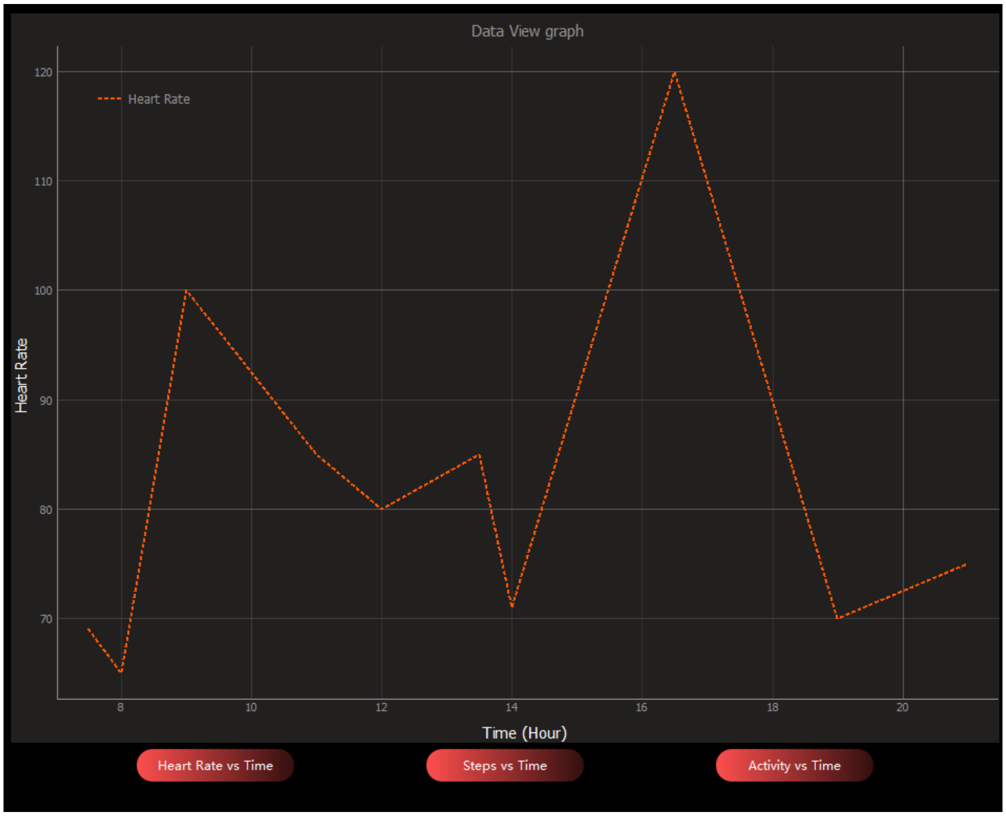

Figure 16: Generated Graph for Heart Rate vs Time

B Hardware Interface

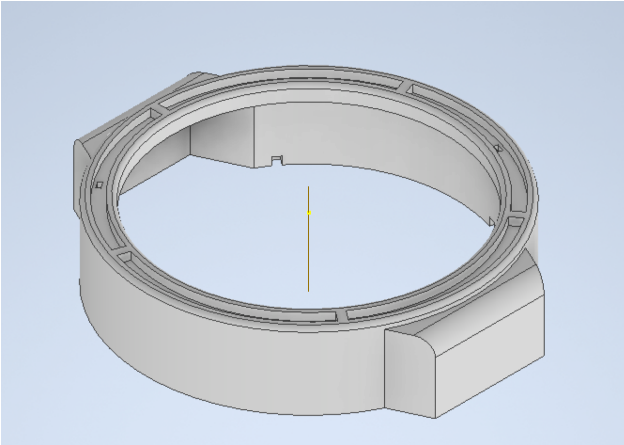

Figure 17: CAD Model of Case for TFT Display

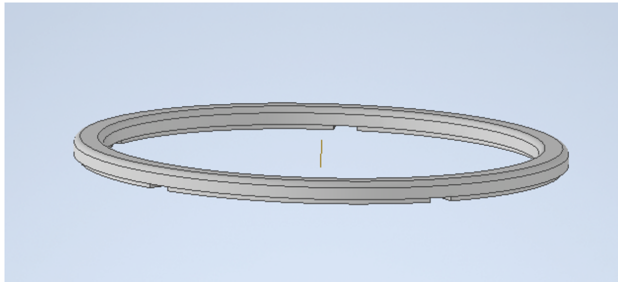

Figure 18: CAD Model of Touch Sensor (Bezel)

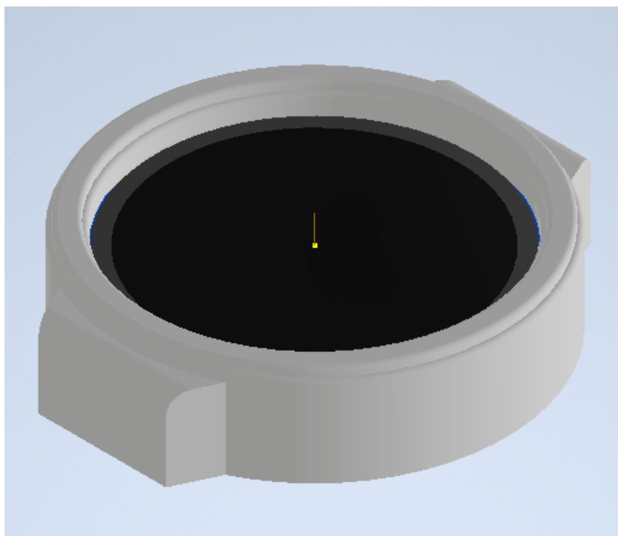

Figure 19: CAD Model of Watch Assembled

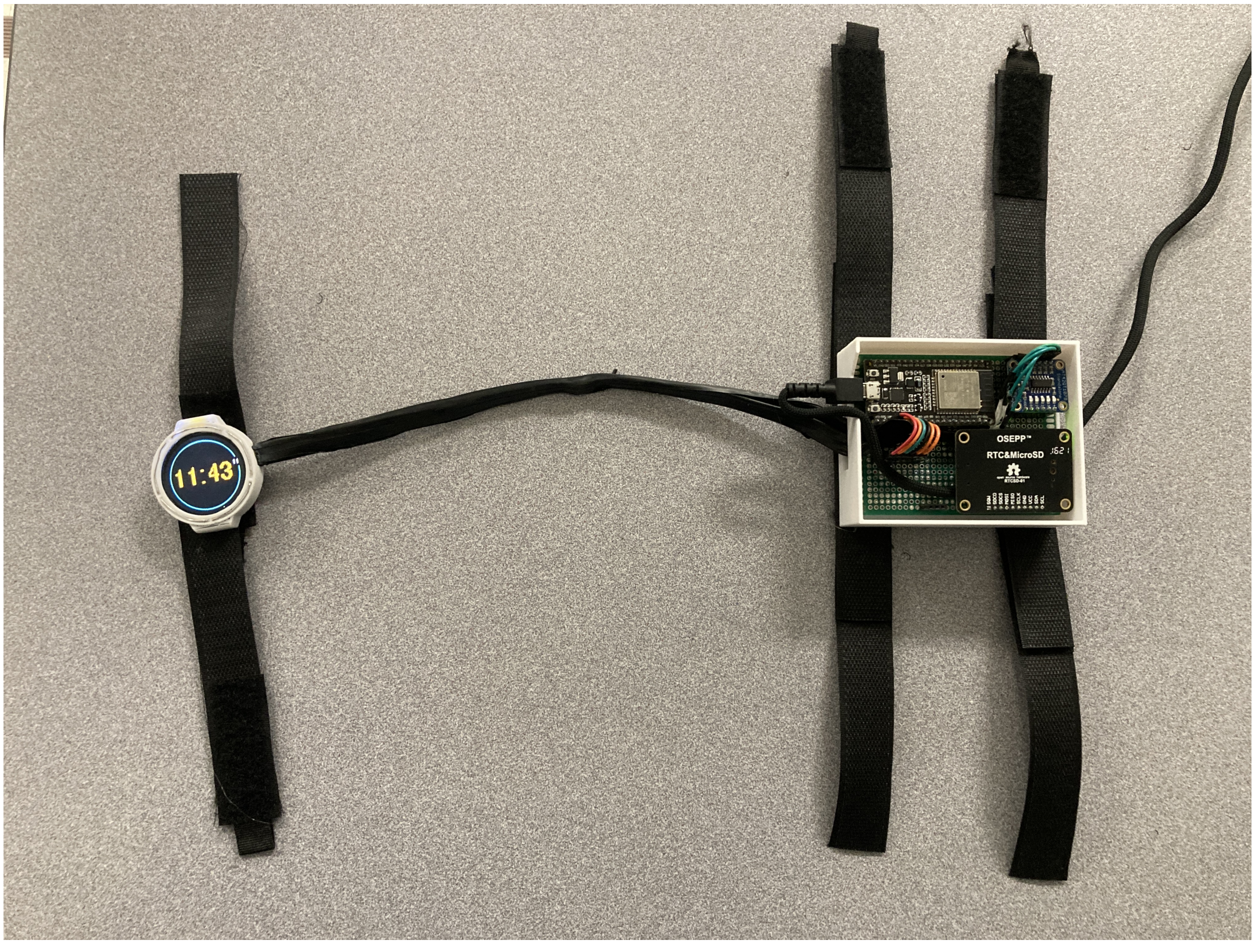

Figure 20: Overall Hardware Design

Hardware Component	Description
Custom PCB	Custom PCB designed to fit in activity tracker.
Touch bezels	Custom 3D printed touch bezels for user interaction with the activity tracker.
Outer casing for TFT display	Designed using Autodesk Inventor and 3D printed.
AT42QT1070-SSUR	Off-shelf microchip for capacitive touch sensors, used in touch sensor schematic.
MPU 6050	Off-shelf accelerometer and gyroscope.
ESP32-WROOM	Off-shelf microcontroller for activity tracker.
DS1307 RTC	Off-shelf real time clock.
Waveshare 1.28 LCD-192 display	Off-shelf TFT display used in activity tracker.
Pulse Sensor	Off-shelf plug and play heart rate sensor.
LiPo battery	Generic off-shelf LiPo battery used for smart watches.
TP4056 Li-Ion BMS	Off-shelf constant-current/constant-voltage linear charge for battery, used in LiPo schematic.
DW01A-G	Off-shelf battery protection IC to protect battery from overcharge, used in LiPo schematic.
USB type-B charger	Generic off-shelf usb to type-B charger to charge device.
MicroSD card	Standard off-shelf microSD card.
SDCARD connector 473521001	Off-shelf microSD connector.
Watch straps	Generic watch-straps for strapping device onto the wrist.

Table 6: Components of Hardware Design

C Electrical Components

Module	Electrical component
MPU 6050	• Capacitors (2nF, 10nF, 100nF) • Resistors (4.7k ohms)
Touch sensor	• Capacitors (0.1uF) • Resistors (470 ohms, 10k ohms)
RTC	• Capacitors (15pF, 100nF) • Resistors (4.7k ohms)
microSD Card	• Capacitors (100nF) • Resistors (10k ohms)
LiPo Battery	• Capacitors (100nF, 10uF) • Resistors (100 ohms, 1k ohms, 1.2k ohms) • FS8205 MOSFET

Table 7: Electrical Components of modules from PCB schematic

D Communication Protocols

Bluetooth communication was implemented using socket programming in Python. The library PyBluez was used to initialize sockets and to establish the connection between the host computer and the device. The host computer directly connects to the device securely using a pin, and data is grabbed from the onboard microSD card and transferred to the computer using bluetooth-serial communication. Bluetooth was also used to send various data to the device including configuration files, formatting SD card, and resetting device.

E Reflection

The information in this section will be used to evaluate the team members on the graduate attribute of Problem Analysis and Design. Please answer the following questions:

1. *What are the limitations of your solution? Put another way, given unlimited resources, what could you do to make the project better?* (LO_ProbSolutions)

   This is a difficult question to answer. Given unlimited resources, the Back End Developers would have many more options available in fundamental design, and may have pursued a different design altogether — however going forward with this question it is assumed that this question refers to the current design on hand.

   There are many forms of ”resources” that have to be managed during an engineering project. Cost, time, testing opportunities, and many more constraining factors can be considered resources. Let us consider cost and time, as those have the largest and most obvious impacts on the project.

   Given an unlimited budget, the face of the EMAnator likely would have been a touchscreen, as the cost of a touchscreen was prohibitively high and we had to find a workaround using nearby capacitive touch sensors instead. In addition, we would have kept ordering test PCBs of our designs as we iterated through different versions. This would have allowed us to test individual components and wiring routes as we constructed the final design. As cost is limited, we have to finish the whole design first, and proceed to order a very limited number of test PCBs on which we must test all aspects of our design. We will then revise the design to compensate for issues found on the test boards, order the final set, and pray that they work as intended. We would also consider adding an operating system to the device to make it ”smart”. Currently our device has a very limited number of functions that fit tightly into our requirements. An OS would enable us to expand the functionality of our device beyond its current borders.

   If the design could have taken place over an infinite amount of time, there are additional possibilities that we could consider. Primarily, we could investigate using and shrinking down a more powerful microcontroller. Currently, the type of microcontroller that we can use is extremely limited in its capabilities. However if we wish to upgrade to a more powerful one (e.g. a Raspberry Pi), we would have to place a large number of auxiliary components necessary for the functioning of the more powerful (and more needy) processor. This would have taken a large amount of time; as finding reasonable space on a PCB and routing components like these is notoriously time consuming.

Obviously there are many new and exciting possibilities for this project should certain resources be unlimited. But overall, we are satisfied with the design that we have made given the constraints that have been placed on us. Should we decide to continue developing this device past the capstone course, we may return to these options at a certain point.

2. *Give a brief overview of other design solutions you considered. What are the benefits and tradeoffs of those other designs compared with the chosen design? From all the potential options, why did you select documented design?* (LO_Explores)

   During the initial phases of the design process, we encouraged each other to throw around as many design ideas as we could. Here is a short list of a few we considered, along with a few of their pros and cons:

   - Anklet Activity Tracker
     Pros:
     - Discreet and unobstructive to daily activities.
     - High-quality data available regarding motion of legs (steps, jumps, falls, etc.).

     Cons:
     - Difficult to reach for people with difficulty bending over.
     - If designed poorly, can potentially look like a prison ankle monitor.
     - Difficult for a user to read any data displayed on a screen on the anklet.
   - Waist-Mounted Activity Tracker
     Pros:
     - Being close to the core of the user, the maximum weight of the device can be greatly increased.
     - Easy access to those with difficulty bending over, or with other movement related issues.

     Cons:
     - Located in a hard-to-hide location, and may get in the way of reaching below the waist.
     - Incompatible with certain clothing.
   - Bracelet Activity Tracker
     Pros:
     - Extremely discreet.
     - High-quality data available regarding motion of arms (walker use, exercise, etc.).
     - Not obstructive to daily activities.

Cons:

  - Interacting with a small-surface area bracelet may be difficult for those with movement issues.
  - Small size reduces battery capacity options.

- Full Body Suit Tracker

  Pros:

  - Highest fidelity data possible, collecting data from every point on the body.
  - Difficult to misplace.

  Cons:

  - Prohibitively expensive.
  - Easy to damage.
  - Many people would be uncomfortable wearing a full sized-body suit during all their daily activities.

- Mobile App

  Pros:

  - Inexpensive.
  - Flexible; meaning we can modify it according to new requirements whenever necessary.
  - Many are already extremely familiar with activity tracking apps; onboarding process will not be difficult.
  - Can be linked to off-the-shelf smartwatches with fantastic activity collecting technology.

  Cons:

  - Not a mechatronics solution.

Why did we pursue the smart-watch solution? For two very important reasons; end-user familiarity and end-user acceptability.

The other solutions that we could have proceeded with may have met all the functional requirements and many of the nonfunctional requirements that we specified, but many of them are unfamiliar and possibly confusing to the end user. For example, having to wear a box around one's waist is likely a novel and strange experience to any user, and could make them uncomfortable with using the device in general. In addition, most people have worn a watch before, and are very familiar with their operations. This makes the process of learning how to use the watch simpler and more intuitive.

A smart-watch was also deemed the most acceptable solution to an end user. It would be difficult to convince anyone to wear a sensor covered spandex suit everywhere they went in their daily life, for a period of up to 14 days. A watch is familiar, socially acceptable, and much less embarrassing than wearing a full bodied suit similar to the figure below.

Figure 21: Example of Someone Experiencing a Full Body Suit