Intelligent Wireless Power for Enabling Enhanced Personal Mobility

A Major Qualifying Project

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Abstract

There is a need in the market for smart wheelchairs that measure activity data for wheelchair users. This proposal presents a low-power, wireless sensing system that records data of the environment, movement, and fall detection. It is powered by RF energy harvesting, involving an antenna receiving electromagnetic waves from a transmitter and converting them into DC voltage. This device includes a gyroscope and triple axis accelerometer to record motion data and is powered by a battery during the day for at least 8 hours, as tested by the team. The battery is recharged wirelessly at night when the wheelchair is at a docking station. This proof of concept was implemented successfully and met all the requirements of the project.

Acknowledgments

Our team would like to thank our advisors Professor Alexander Wyglinski and Assistant Professor Bashima Islam. Their guidance throughout the project helped us greatly in creating a product that we are proud of. Without their advice, the project would not be where it is today. We thoroughly appreciate their time, effort, and support throughout the course of the year.

Our team would also like to thank William Appleyard for his expertise on building our plexiglass enclosure as well as the construction of our docking station. His knowledge and skill were very helpful in completing those parts of the project. We are very grateful for all of his time and support.

Additionally, we would like to thank the employees and residents at Cherry Blossom Senior Living for their responses to our interview which provided insight into daily wheelchair use. Their contributions to the creation of our project were extremely valuable.

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We lastly want to acknowledge Powercast for answering our questions over email about their transmitters and receivers and giving us valuable information that allowed us to move forward with our project.

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Executive Summary

Many of the 2.7 million wheelchair users in the United States rely on manual wheelchairs for their independence in mobility, which is an important factor for a person's quality of life [1]. According to the Department of Veteran Affairs, up to 1.7 million people need a smart manual wheelchair, and up to 2 million people need a smart, powered wheelchair [2]. Despite the need for powered wheelchairs – the cheaper, lighter, and more maneuverable manual wheelchairs are more popular as they accommodate the patient's capabilities [2, 20]. The fitness and activity tracking market is currently targeted primarily towards able bodied individuals, and there is not much on the market for wheelchair users. There is a need for a cheap, low maintenance, and long-lasting sensing system that can be easily attached to manual wheelchairs. These low power sensing systems will allow the wheelchair users to track their movement throughout the day. Developing a passive monitoring device for wheelchair users presented many challenges. Firstly, there is a need to record physical activities performed when using the wheelchairs manually. Next, there is a need to remove the hassle of persistently plugging in the wheelchair to charge it. To eliminate this issue, the team focused on charging the batteries by harvesting ambient energy. To better understand the needs of the users, the team interviewed four senior wheelchair users. Here are the main findings:

(i) All of the participants are in their wheelchairs for the majority of the day, and rarely spend time outside.

(ii) All four participants said they would use a device that tracks their movement.

The team researched different types of energy harvesting techniques that are currently being used to convert one type of energy into electrical energy. Here, RF is discussed in greater detail because it was the chosen solution, though solar power and piezoelectrics were also considered. Radio frequency (RF) energy harvesting involves an antenna emitting electromagnetic waves from a transmitter and converting them into DC voltage. The receiver antenna is tuned to a particular frequency to detect those specific electromagnetic waves. Figure A below shows a diagram of the stages of the RF energy harvester system.

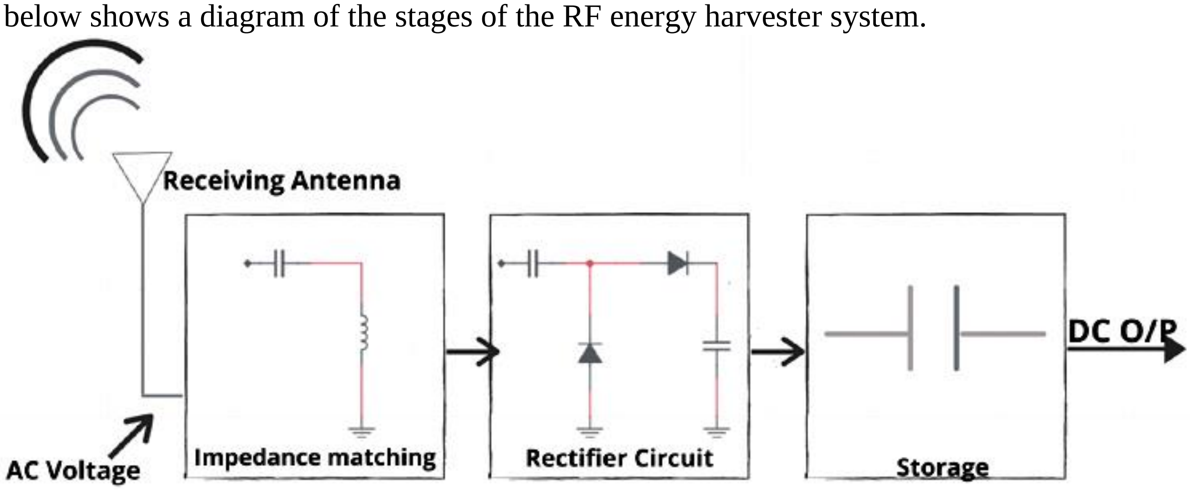

Figure A: *Diagram showing the stages of the RF energy harvester system [26].*

The design requirements are based on what the team wanted to accomplish and were assessed in a tradeoff analysis. The following are the considerations for an ideal product that the team examined. In no priority, size was the first category. It is important that the product does not cause a hindrance to the user of the wheelchair, so great care was taken in making sure the components were small and compact. The team also considered weight as an important factor. The wheelchair should not be weighed down by the product and should be light and compact so that there is no obstruction in the use of the wheelchair itself. The output power was another important feature since there needs to be enough power generated to allow the rest of the system to function properly. This was divided into two categories. The first is availability of energy since it is important for the energy harvester to adequately supply the system with enough energy to run for at least 8 hours. The second is operating duration, which describes how long the product can stay powered and work over a period. Therefore, the user can use the product for a long time without needing to charge it. The next important detail is cost. The team was given a budget of 750 dollars, but to make the product marketable, it must be able to be mass produced. Lastly, the team looked at reliability, because the team wanted a product that they knew they could trust and rely on the system to work consistently. These 5 requirements were put into consideration when researching the different components to design the system.

All of the energy harvesting techniques (solar, piezo, and RF) were small, compact, and lightweight, which is ideal because it can fit on a wheelchair and it will not disrupt the functionality for the wheelchair user. The output power was another important feature, where many of the harvesting techniques faced major issues. The solar panels that were researched were inexpensive and took a substantial amount of time to charge, requiring many continuous hours of direct sunlight. A similar situation was faced with the piezoelectrics, since in those dimensions, it is difficult to generate a significant amount of power. The RF power offers up to 0.43 watts, and conveniently the RF technology is all compact in one chip. Another component the team considered is the cost of the product. Solar panels were the cheapest option the team considered, and RF was the most expensive. Lastly, the team weighed the reliability. Solar panels would not work as effectively during cloudy days and nights. For RF, there was not much information found regarding how trustworthy it is, since it is a new form of technology, and advancements are still being made today. Piezoelectrics were the most reliable, with power generated every time the wheel turns. However, the amount of power created would be miniscule at best. When the team began brainstorming solutions, the first option discussed was using a combination of solar power, piezoelectrics, and RF power. However, the combined price of the harvesters was more expensive than other solutions. Instead of a combination, RF power as the sole harvester would be pursued for generating power. Although the specialized receiver modules from Powercast were expensive, the advantages of this solution outweighed the disadvantages. There needed to be a way that this power would be stored using an exterior battery or a capacitor. When a minimum of 3.3 volts is applied to the OpenLog Artemis and the total charge that needs to be stored for 8 hours is 432 coulombs, then a 131 farad supercapacitor would be required. Additionally, a DC-DC converter would be needed to balance out the voltage. This was impractical, since the OpenLog Artemis board was the primary load for the circuit, but more voltage would be drawn to the DC-DC converter and supercapacitor combined. Therefore, the team decided to switch to batteries which have a much lower charge/discharge rate. By the team's calculations, an 80-160 milliamp hour battery was needed in order to meet the time requirement. The device also contained a compact SparkFun OpenLog Artemis board which detects and logs motion data. The input voltage ranges from 3.3 volts to 6.5 volts, and the maximum power necessary is 0.13 watts [17]. When the wheelchair is connected with the docking station, the RF harvester charges the battery. When the wheelchair is not engaged with the docking station, the battery charges the OpenLog Artemis board. All the components of the circuit that are connected in parallel by the custom PCB. It has 2 buses – one for power, and one for ground. This entire system was combined, and a block diagram, as shown in Figure B, was created.

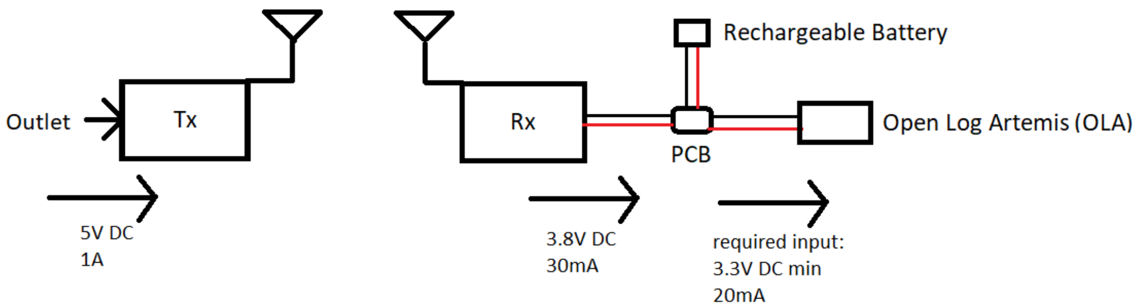

Figure B: *Block diagram of the system. Diagram shows how the RF power is used to power the rechargeable battery, and how the battery powers the OpenLog Artemis board.*

Figure C shows how the voltage applied to the OpenLog Artemis changed with respect to the distance between the transmitter and receiver. Since the minimum operating voltage of the OpenLog Artemis is 3.3 volts, the testing determined that the distance cannot exceed 8 inches apart.

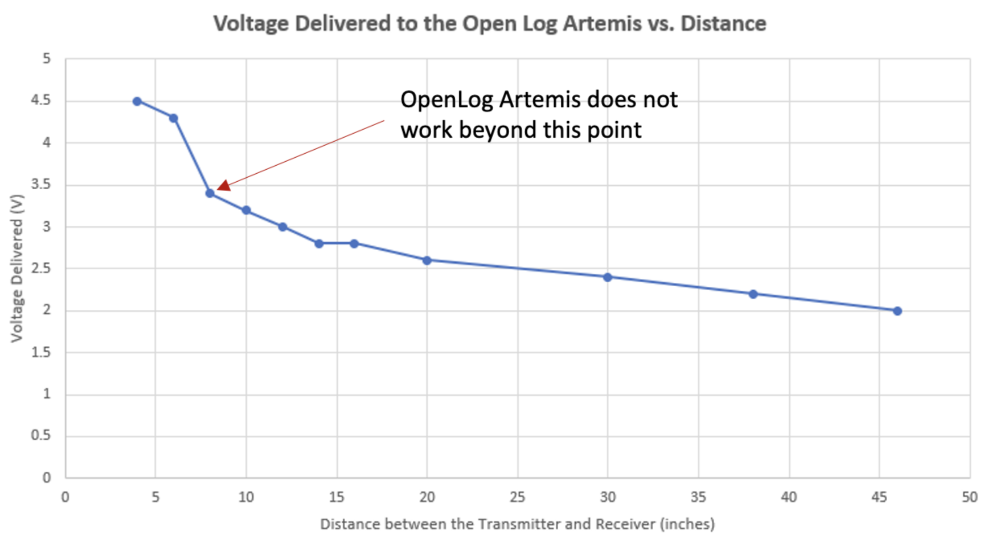

Figure C: *Testing the voltage applied to the OpenLog Artemis as the distance increased.*

To make sure the system ran for a full working day, the team decided it would be best to run the system for 8 hours. When testing the discharge of the battery, shown in Figure D, the battery started with about 3.8 volts to charge during the day. At the end of the day, it was down to 3.6 volts, which is well above the 3.3 volts minimum. This means realistically the system can run for more than 8 hours, which is an advantage since that provides the user with a safety buffer. Figure D shows the discharge of the rechargeable lithium battery over the course of 8 hours. Figure E shows the charging of the lithium battery over the course of 8 hours. These graphs show that realistically the system can run for more than 8 hours, which is an advantage since it provides the user with a safety buffer. This was repeated with similar results, showing that the range of charge left after use during the day is reproducible.

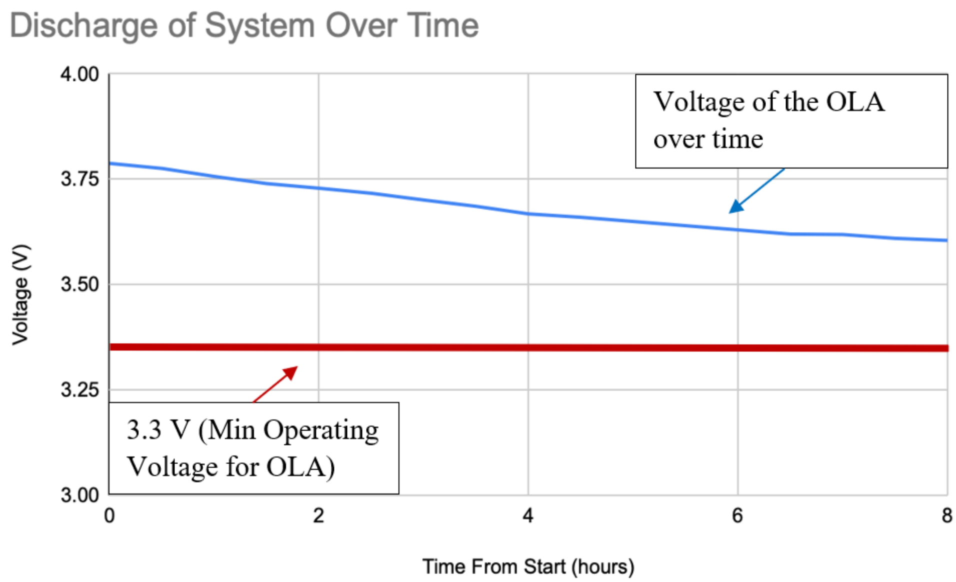

Figure D: *Discharge of Rechargeable Lithium Battery over 8 hours.*

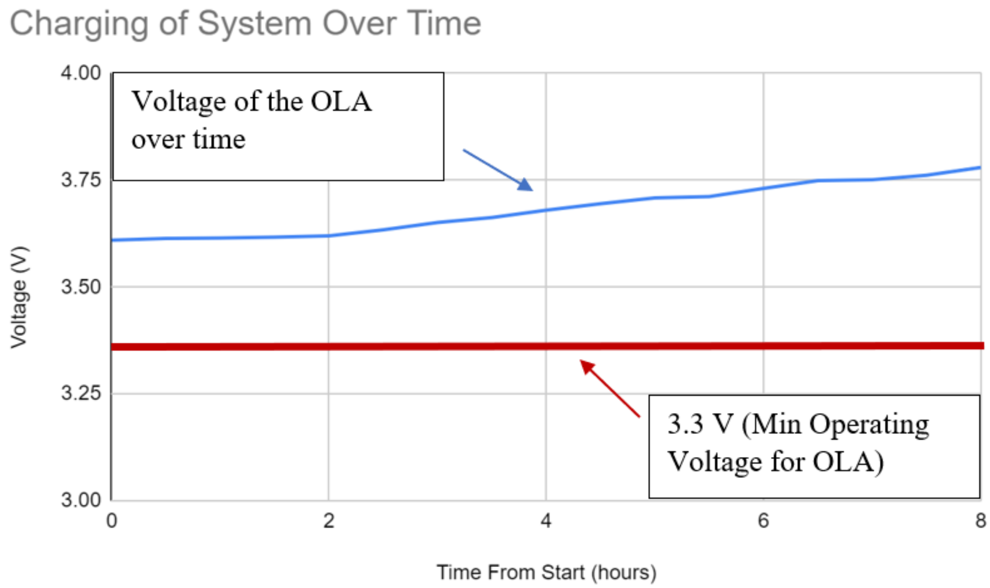

Figure E: *Charging of Rechargeable Lithium Battery over 8 hours.*

To test the accelerometer, the wheelchair with the device was taken on a test run around campus. Figure F shows this downhill acceleration on concrete, which demonstrates how fast the team was accelerating. At a certain point during testing, the team had stopped to make some assessments. This can be seen in the graph when there is a distinct pause in the data collection at around 541-571 data points, which amounts to 54 seconds in the team's testing where each data point occurred within 1/10 of a second. This is the raw and unfiltered data, but the pause shows the baseline, and that the average of the data points when the wheelchair is not paused will still be above the baseline, showing that this information is still valuable and informative.

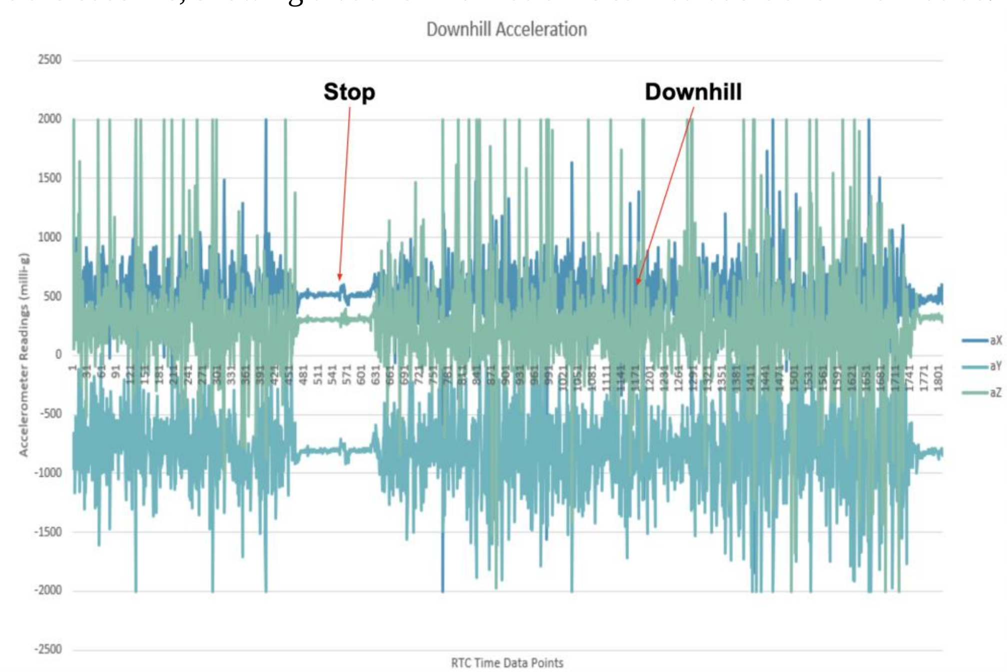

Figure F: *Accelerometer readings when the wheelchair accelerated downhill.*

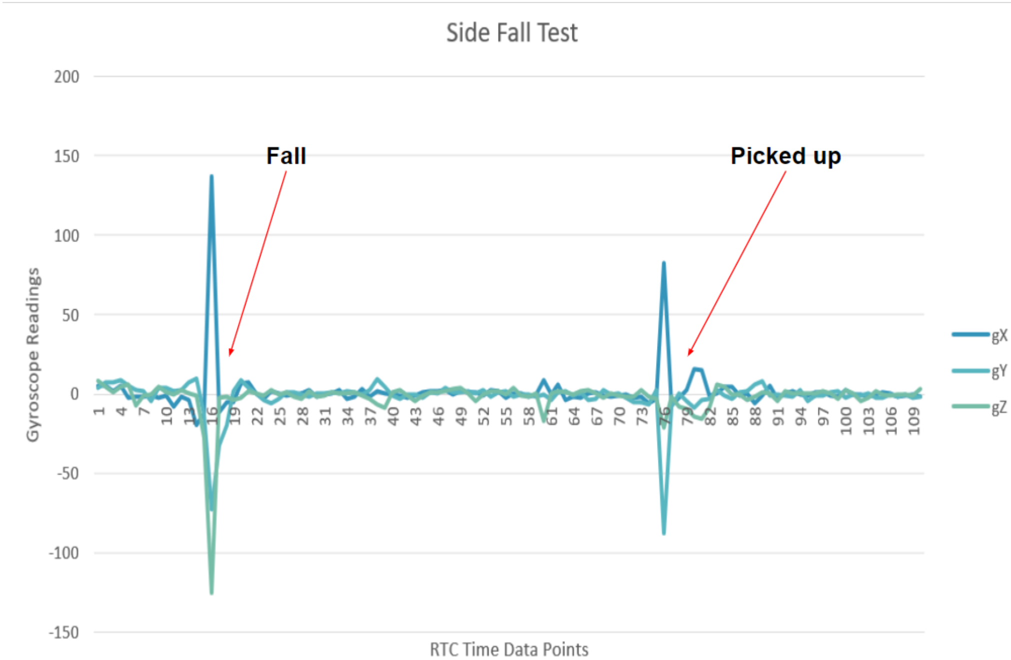

Figure G: *Gyroscope readings when the wheelchair fell on its side.*

The team also used the features of the gyroscope to test fall detection, shown in Figure G. This was done by toppling the wheelchair on its side. The first spike shows the fall, and the second spike indicates when the wheelchair was lifted up off the ground. This is a good application of the gyroscope, as the graph provides a clear indication that the wheelchair user is falling since the wheelchair does not rotate ideally. The team designed a PCB on Eagle, as seen in Figures H and I, with two buses, one for power, and the other for ground. The lithium polymer battery, the OpenLog Artemis, and the receiver were connected to the PCB.

Figure H: *Picture of PCB used to connect components of the wheelchair device.*

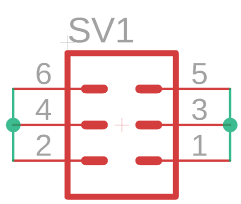

Figure I: *Schematic of the PCB.*

It was decided that a plexiglass box would be the best option for the enclosure because it would protect the system, the circuit can still be seen from inside the box, it is visually appealing, and it can be easily mounted to the wheelchair. The lengths of the components were measured and the team decided that a 8” by 6.5” by 2.5” box would be sufficient. To attach the box to the wheelchair, two ring clamps were glued to the back of the box. Figure J below shows this circuit which is housed in the plexiglass.

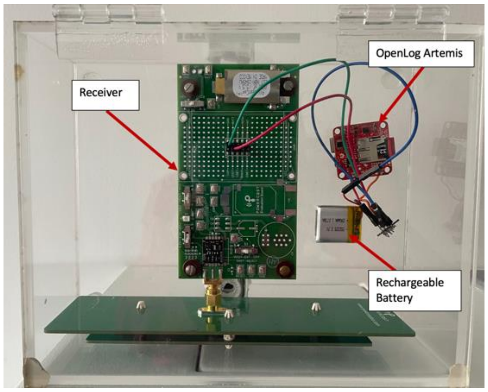

Figure J: *Image of wireless wheelchair system housed in plexiglass.*

Figure K: *Image of the system attached to the wheelchair and parked at the docking station.*

Next, the team decided to create a docking station to have the transmitter in one place that would not be run over by the wheelchair user. Plywood was the most easily accessible, durable, and easy to cut, therefore it was chosen. The team created a platform 1.5" off the ground, with two slits in it for the wheels to slide in. The wheels stop at the midway point of the station. The transmitter is also embedded in the docking station, and the wheel stops ensure that the transmitter and receiver are aligned, maximizing the receiver voltage. Figure K shows the wheelchair with the docking station in its full form.

Overall, this device helps wheelchair users and their caretakers to analyze the recorded data, so that they can better understand their movements and activities throughout the day. Users can also use this device during the day without worrying about the device running out of power and can easily recharge the device during the night.

Chapter 1: Introduction

1.1 Motivation

Many of the 2.7 million wheelchair users in the United States rely on manual wheelchairs for their independence in mobility, which is an important factor for a person's quality of life [1]. There is no doubt a need for smart wheelchairs, especially with the development of new technology in so many fields. According to the Department of Veteran Affairs, up to 1.7 million people are in need of a smart manual wheelchair, and up to 2 million people need a smart, powered wheelchair [2]. Sensing wheelchair activities embeds valuable information regarding the users' health, habits, accessible facilities, and even the environment around them.
The fitness and activity tracking market is currently targeted primarily towards able bodied individuals, and there is not much on the market for wheelchair users. To help with this issue of accessibility, some sensing devices have been made to record metrics of the wheelchair user's experience. However, most of such smart wheelchairs are costly and not easily available [3]. They are mostly battery-powered which have an operating duration of only 3-4 hours [4-8].

There is a need for a cheap, low maintenance, and long-lasting sensing system that can be easily attached to manual wheelchairs. These low power sensing systems will allow the wheelchair users to track their movement throughout the day, similar to fitness tracking technology for able bodied people such as Fitbits. The team's system provides statistics of movement, environment, and fall detection. This will increase the safety of the wheelchair user and improve the quality of life.

1.2 Current State-of-the-Art

The team researched prior art that had similar attributes to their project. This section highlights three papers that were discovered. Two of the papers pertained to collecting data from sensors attached to a wheelchair during wheelchair basketball games [9], [10]. The third paper discussed an app for wheelchair users called WheelieMap [11].

In [9], the design and implementation of the sensing system, SpokeSense, was explained. It was primarily used to analyze wheelchair basketball players' performances. They used two sensors mounted on the wheels to sense motion and audio information. This is intrusive and does not account for the privacy of the user, so the team decided not to use it. The gyroscope was used to measure distance and speed with less than 5% error, which inspired the team to look into gyroscopes for their project implementation. To store these types of data for long amounts of time, one method that was researched was a miniaturized data logger (MDL). Prior research by the authors had shown that this option was not the best one for their application. It was explained that MDLs are not very accurate in estimating motion during peak activity levels, and the information collected can only be reviewed a long time after data collection. For the SpokeSense system, they opted to send the data over WiFi to a computer in order to analyze it. The MQP team also considered an MDL, but ultimately decided not to use it, as WiFi is not available everywhere and it did not work for the authors themselves, and therefore is not an universal solution.

In [10], the article spoke about wheelchair fitness tracking devices, specifically regarding the need for these devices, and their scarcity in the market. This article interviewed basketball players and asked them what they thought was the best use of the data collected. Similar to the team’s device, the players were looking for distance, top speed (velocity), and acceleration (both linear and angular). The team implemented these elements into their final product as well. The paper mentions there is a lack of such products in the market since many are not interested in the motion of wheelchair users, and how that can apply to sports, medicine, and other beneficial use cases. Much of the existing tracking technology is limited to able bodied users, and thus it is difficult to adapt it to wheelchair users. The team recognized that the device they were creating for this project does not exist in the market.

The researchers used MDLs, contrary to the approach that the other researchers had taken in the first paper. The information collected by these data loggers is crucial since it is used by the coaches and the personnel staff that worked with the athletes to improve their performance. The data can also offer some real time feedback with evidence, which helps them understand what they can do better in the game using in-game statistics. There was also an interview component to their research, where they asked a series of questions regarding privacy as well as social and practical aspects of using the data. In terms of privacy, the users did not seem to mind if the information was not private. In fact, the athletes were quite open to sharing their data with others, so that aspiring wheelchair athletes could use their data to see how they compare to the professionals.

The product developed in [11] is called the WheelieMap, which is used for mapping out and documenting areas that are more inaccessible to wheelchair users. This documented data is then shared with other users with disabilities and the relevant authorities. This product consisted of three main components – the mobile app, the video segmentation algorithm, and the user interface. The qualities that users liked about WheelieMap that the team deemed to be the most relevant to their project included ease of use, efficiency, and user convenience. This paper also discussed how there were not a significant amount of products designed for wheelchairs, such as those to track locations. From the research, the team discovered that there is a lack of prior art that represents exactly what the team is creating.

1.3 Design Challenges

Developing a continuous and passive monitoring device for wheelchair users presented many challenges. In this work, the team focused on three of them.

(1) Firstly, there is a need to record physical activities performed when using the wheelchairs manually. Currently, the major form of collecting this data is through self-report questionnaires, though it is important to note that they tend to lend themselves to falsification, either through poor memory or simply an exaggeration [12]. Therefore, it was statistically difficult for the researchers to gauge any interest in such a wheelchair device, or the need for it. However, these resources are important for individuals using wheelchairs, and acknowledging the lack of information is the first step towards recognizing that a solution is imminent.

(2) Next, there is a need to remove the hassle of persistently plugging in the wheelchair to charge it. To eliminate this issue, the team focused on charging the battery by harvesting ambient energy.

(3) Finally, one consideration the team made was whether the harvester application would work indoors as well as outdoors, for a universal application for the team's device. To better understand the needs of the users, the team interviewed four wheelchair users living in Cherry Blossom Senior Living in Columbus, Ohio. These interviews allowed the team to understand the best way to create a wheelchair sensing device. The questions asked by the team to the residents of Cherry Blossom Senior Living, along with the IRB number for this interview, can be referenced in Appendix A. Here are the main findings:

(i) All of the participants are in their wheelchairs for the majority of the day, and rarely spend time outside.
(ii) They travel in their wheelchairs to mealtimes, daily activities, and to the restroom.
(iii) All four participants said they would use a device that tracks their movement.

1.4 Product Design

The team's proposed solution includes both minimum requirements (needs) and add-ons (wants). The minimum requirements of this project involve successfully using RF at a frequency of 915 megahertz as a wireless power source of 0.43 watts for the wheelchair device at a distance of no more than 8 inches between the transmitter and receiver. Wheelchair users do not often remember that they have to charge their wheelchair, especially if that is something they have never had to do before. The add-ons of this project include creating an enclosure for the system that protects it from water and does not block the RF frequency. Additional add-ons not pursued by the team include generating power through an additional method (piezo, solar, or both), being able to dynamically change the sampling rate according to the user's speed to conserve power and adding an amplifier to the wireless device.

The team's design of the product involved using a 9-Degree of Freedom data logger (SparkFun OpenLog Artemis board) in conjunction with a RF receiver and transmitter pair (Powercast P1110 and TX91503 respectively) for harvesting energy [13-14]. The data logger consists of an accelerometer, a gyroscope, and a magnetometer, and is used to measure a user's movement, speed, and other factors that a user can deem useful [15-16]. The SparkFun OpenLog Artemis is both compact and includes all the necessary components for detecting and logging motion data for the final device [17]. The OpenLog Artemis board includes built-in sensors and a data logger [15-16]. This board also has active, sleep, and deep sleep modes to conserve power as necessary [17]. The SparkFun OpenLog Artemis board will be charged using a lithium polymer (LiPo) rechargeable battery. The team chose a rechargeable battery rated for 3.7 volts and 270 milliamp hours, since it fit the specifications of the other circuit components [18]. While the user is not using the wheelchair, the wheelchair is placed at a docking station. At this docking station, the LiPo rechargeable battery is charged using the RF receiver/transmitter duo. When out of range of the docking station, the wireless device will be powered with the LiPo battery.

Originally, for the OpenLog Artemis board to be charged, a USB-C connection was going to be soldered to the evaluation board to connect to the OpenLog Artemis board [19]. However, as a design choice, it was decided that the OpenLog Artemis board would be connected to the evaluation board in parallel to the receiver's V_{out} pin to the OpenLog Artemis's V_{in} pin and connecting their grounds together.

1.5 Paper Organization

This paper will first cover current wheelchair technology and other relevant technologies used in this project (Chapter 2). Then, the proposed design will be explained in detail (Chapter 3), including design requirements, the different options that were thought of, and the design option that was pursued with a list of its strengths and weaknesses. After that, the timeline of the project will be outlined along with Gantt Charts, milestones, and deliverables (Chapter 4). Finally, the results and analysis of the project will be identified (Chapter 5). Future work for this project as well as the conclusion (Chapter 6).

Chapter 2: Overview of Energy Harvesting Techniques

Despite the obvious need of powered wheelchairs – the cheaper, lighter, and more maneuverable manual wheelchairs are more popular as they accommodate the patient [2, 20]. As many users do not prefer all the interactive technologies of automatic wheelchairs, they are reluctant to spend additional money for automated wheelchairs. Though they appreciate and want the sensing capabilities for their health benefits, they do not find the high cost justifiable. In this case, a smart, powered wheelchair that is autonomous is not always necessary and the user may not want to spend more money than is needed. This chapter presents an overview of various energy harvesting techniques and why the team ultimately chose RF as the energy source for the project.

2.1 Energy Harvesting Techniques

Different types of energy harvesting techniques are used to convert one type of energy into electrical energy. The three harvesters that were explained include solar power, piezoelectrics, and RF power.

2.1.1 Solar Power

The sun gives off energy which comes to Earth as heat and light. This light is collected by solar panels, either through a glass cover with a coating, or the use of curved mirrors. In the solar cell, also known as the photovoltaic cell, there are tubes with oil in them. The heat and light from the Sun heats up the oil. That heat is used to turn water, which is flowing through pipes into steam. The steam then turns a turbine which creates electricity. On average, one industrial solar panel can generate 200 watts of electricity [21]. Figure 2.1 below shows a diagram of how solar power is generated [21].

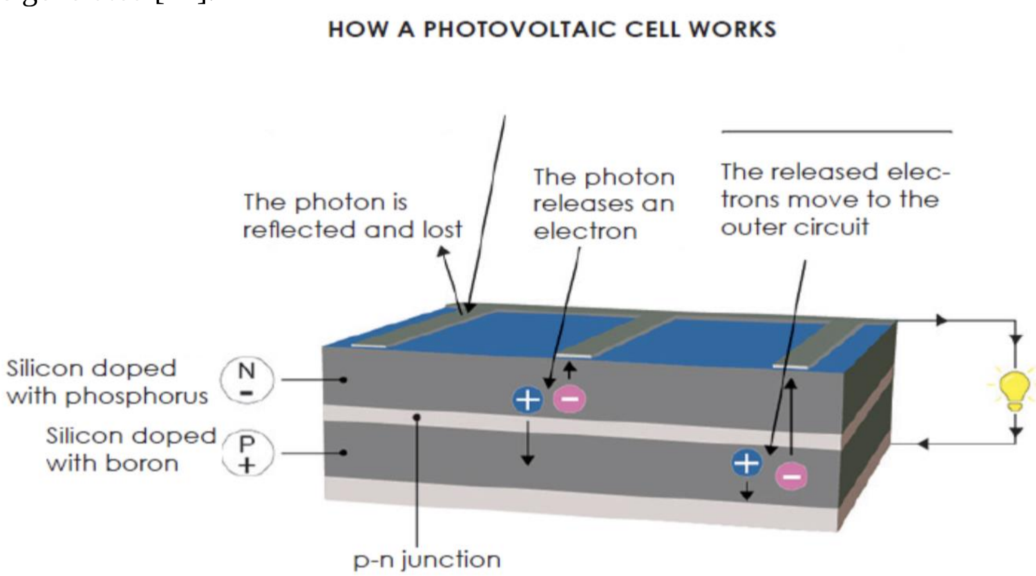

Figure 2.1: *Diagram with the different components that make harvesting solar power easier [21].*

2.1.2 Piezo Power

Piezoelectric transducers were first made out of quartz crystals, but are now commonly composed of ceramic, patented material [22]. When the material vibrates from oscillating due to applied stress, an AC voltage is produced [23]. The AC voltage can be converted to DC voltage and used to power sensors. Essentially, piezo power converts kinetic energy in the form of vibrations into electrical energy. Piezoelectrics are best used to power sensors that are connected to IoTs involving human activity. This is because piezo power can use the energy humans generate through motion and convert that into electrical energy. For example, Zhao et al. put piezoelectric material in shoes and generated 1 milliwatt of power while a person walked [24]. Resonance frequency is a key property of piezos. It is the frequency at which the piezoelectric material vibrates that produces the maximum output power [25]. Figure 2.2 below shows a diagram displaying the cantilevered beam for piezo power [25].

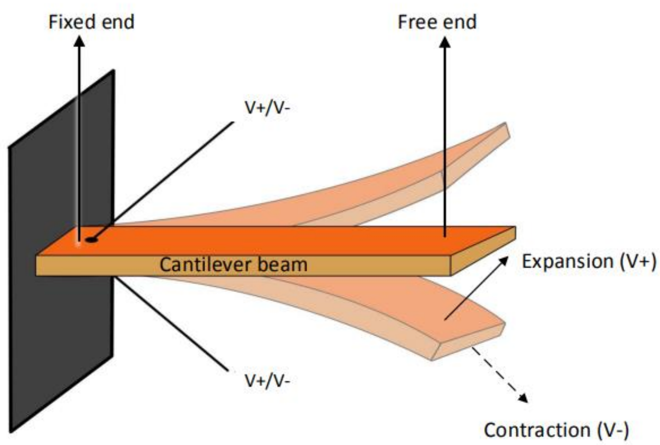

Figure 2.2: *Diagram displaying the cantilevered beam for piezo power [25].*

2.1.3 RF Power

Radio frequency (RF) energy harvesting involves an antenna emitting electromagnetic (EM) waves from a transmitter and converting them into DC voltage. The receiver antenna is tuned to a particular frequency to detect those specific EM waves. To be an efficient antenna, the antenna should be small and have a high gain [26]. The energy captured by the receiver antenna then goes through an impedance matching circuit. The impedance matching circuit, as its name implies, causes the load impedance and the source impedance to “match,” thus maximizing the amount of power transferred from the antenna to the rest of the RF energy harvesting system [26]. The power is then transferred to the rectifier circuit. This circuit is used to convert the AC voltage into DC voltage, which can then be used as a source to power different devices. In some systems of RF energy harvesting, the antenna and the rectifier circuit are combined into a single component, called a rectenna. The most important component of the rectifier circuit is the diode, as the diode allows the current to only flow in one direction. Diodes with fast switching times are commonly used for RF energy harvester systems [26]. This is because their fast-switching times can keep up with the high frequencies of the RF harvester. The power is then transferred through a voltage multiplier circuit which includes many capacitors and diodes. This circuit helps to maximize the amount of DC voltage produced. Below, in Figure 2.3, is a diagram that shows the stages of the RF energy harvester system as described previously [26].

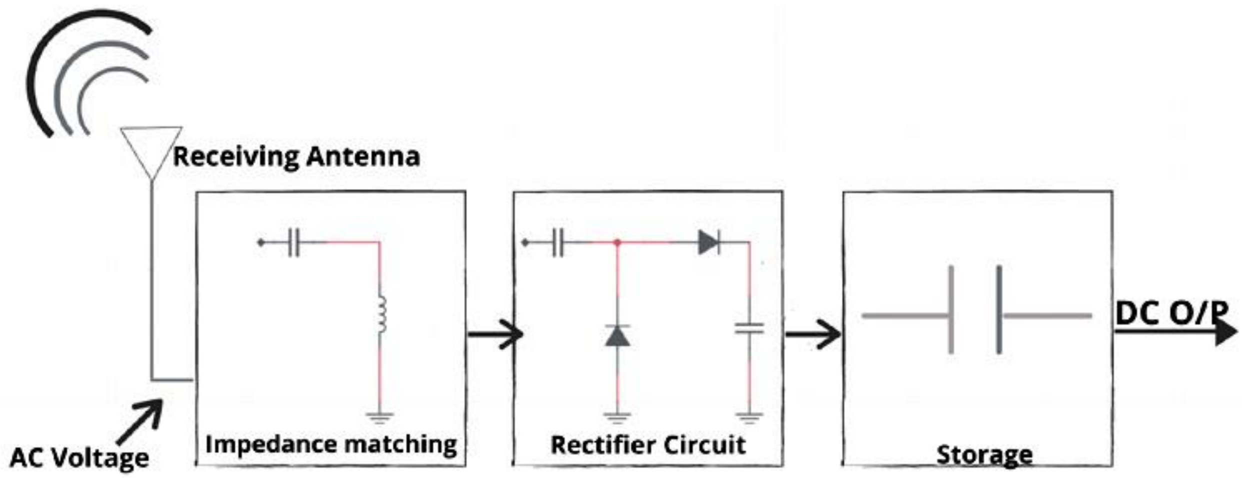

Figure 2.3: *Diagram showing the stages of the RF energy harvester system [26].*

The sources of the electromagnetic waves used in RF energy harvesting can be from any device that transmits RF waves. These sources include radio stations, TV stations, satellites, mobile devices, and wireless LAN transmitters or Wi-Fi [27]. Overall, RF energy harvesting can be used for many applications, including applications in the Internet of Things (IoT), charging mobile or other portable devices wirelessly, and providing a wireless power source [27]. The amount of power, as well as other statistics that the team measured can be referenced in Table 3.1.

2.2 RF Power in Different Scenarios

RF power depends on the transmission and reception of electromagnetic waves and signals. In an ideal situation, there would be no obstacles impeding the transmission of the signals, and the signal would be received with no interference. However, the signal strength for radio frequency waves may decrease, which is known as attenuation or path loss [28]. The amount of attenuation can change depending on what medium is between the transmitter and receiver. It also varies based on signal frequency and range. When RF power is used for indoor applications, the attenuation may increase due to the signal bouncing off common obstacles such as walls, windows, or people [28]. The following equation can be used to calculate path loss (PL) in decibels (dB) [28]:

$$PL = 20 \cdot log(\frac{4 \cdot \pi \cdot r}{\lambda}) \; where \; \lambda \; = \; \frac{c}{f} \qquad \text{(Eq. 1)}$$

In this equation, λ is the wavelength in nm, *c* is the speed of light which is $3 \cdot 10^8 \frac{meters}{second}$, and f is the frequency in hertz, and *r* is the radius in meters.

Outdoor applications typically follow a free space model, shown in the following equation [28]:

$$Range = \frac{\lambda}{4 \cdot \pi} \cdot 10^{\frac{PL}{20}} \quad \text{(Eq. 2)}$$

Signal fading is one variation of attenuation. It can be caused by different interferences, such as disruptions to the line-of-sight (LOS). Shadowing is a phenomenon where the received signal power varies because of obstacles blocking the propagation path; this also contributes to signal fading.

Air and distance are two factors that account for a significant portion of the path loss that is faced by systems using RF. There is more loss in power the further the transmitter and the receiver are, so air can be considered the first obstruction in indoor path loss [29]. There are three factors to consider when it comes to evaluating and minimizing indoor path loss. These include transmit power (how much power the transmitter emits), receiver sensitivity (the minimum signal strength at which the receiver can detect), and antenna gain (how much gain the antenna can provide to maximize the amount of power entering the system). The frequency chosen also affects the attenuation. The lower the frequency, the better suited it is to handle obstacles such as air and objects [29]. To best measure how a particular transmitter-receiver pair is performing, a parameter called Link Margin is often used [29].

Link Margin = Transmit Power - Receiver Sensitivity + Antenna Gain - Path Loss (Eq. 3)

This parameter measures how soon the connection will break. If there are more obstacles in the way, the link is going to break sooner. If the Link Margin is greater than zero, this means that there is a successful connection between the transmitter and the receiver.

2.3 Chapter Summary

This chapter covered the different energy harvesting techniques such as solar and piezo, and the applications of RF were further discussed. This specifically explained why RF power appealed to the team. Section 2.2 describes the process of how RF energy can be harvested and optimized. For RF energy, the transmitter emits EM waves and the receiver antenna captures them. The impedance matching circuit matches the source and load impedance after which the rectifier circuit converts the AC voltage to DC voltage. The voltage multiplier circuit then maximizes the DC voltage which is outputted. This process is what the team needs in order to implement a wireless charging device using RF power.

Chapter 3: Proposed Design

This chapter will cover the proposed solution that the team finalized based on the problem and market research done previously. The team researched different options and came to a conclusion for a finalized design.

3.1 Design Requirements

The design requirements are based on what the team wanted to accomplish which were put into a tradeoff analysis. This trade off analysis was completed before choosing the final components for the device. The following are the considerations for an ideal product the team examined for this project:

1. **Dimensions:** The size and weight were important to the team because it had to be light, compact, and easily fit on a wheelchair without obstructing the functionality.
2. **Cost:** The cost is always an important factor for any project. The team was given a budget of 750 dollars, but to make the product marketable, it must be made cheaper and capable of mass production. Each power source was compared by unit cost.
3. **Availability of Energy:** It is important for the energy harvester to adequately supply the system with enough energy to run for at least 8 hours. The power sources were compared to determine which would be the best fit for the system.
4. **Operating Duration:** The operating duration describes how long the product can stay powered and work over a period. Therefore, the user can use the product for a long time without needing to charge it.
5. **Reliability:** The ideal product should be reliable, meaning that it is durable and long-lasting.

   These 5 requirements were put into consideration when researching the different components to design the system.

3.2 Design Options

In this section, different components were compared to decide which would work best for the team's application. The components that the team focused on were energy harvesting sources and sensing modules.

3.2.1 Choosing the Energy Source

The team began by doing baseline research on the three types of power with the potential to charge the system – solar, radio frequency (RF) and piezoelectric. The team focused on the five categories listed above during the tradeoff analysis when evaluating these power strategies. The team discovered each of the power harvesting techniques were marked with green, as can be seen in Table 3.1. This meant that all of the techniques were small and compact, which is ideal for implementation in the project. The team also considered weight as an important factor. All of these power options were lightweight, so all the power sources are still an ideal candidate.

The output power was another important feature since there needs to be enough power generated to allow the system to function properly. This is where many of the harvesting techniques faced major issues. The solar panels that were researched were inexpensive, and do not have the high-quality solar cells that can generate the maximum amount of power required of them at the size restraints. Therefore, the cheap solar panels take a very long time to charge, requiring many continuous hours of direct sunlight. A similar situation was faced with the piezoelectrics too, since they too must be small, and in those dimensions, it is difficult to generate a significant amount of power. Installing the piezo devices to produce power would involve placing leaf springs along the wheels of the wheelchair. It would also involve placing the springs such that they would be pressed down as the wheelchair moved. This mechanical challenge, in addition to the fact that piezo does not generate as much power as RF, did not make piezo the most optimal solution for the wireless wheelchair device. The RF power offers up to 0.43 watts, and conveniently the RF technology is all compact in one chip.

Another component the team considered is the cost of the product. For the price, the solar panels were the cheapest option the team considered, with the RF being the most expensive, since there was a need for a transmitter antenna as well as a RF-to-DC converter that could convert the power collected into volts to power the system requirements.

Lastly, the team weighed the reliability. Solar panels would not work as effectively during cloudy days and nights, should the wheelchair user travel at night. For RF, there was not much information found regarding how trustworthy it is, since it is a new form of technology, and advancements are still being made today. Piezoelectrics were the most reliable, with power being generated every time the wheel turns. However, the amount of power created would be miniscule at best. Table 3.1 shows the tradeoff analysis, mentioned previously, conducted for the three proposed solutions of a power source for the wireless wheelchair device.

Table 3.1: *Trade off analysis of the three proposed solutions for a power source of the wireless wheelchair device.*

	Dimensions		Availability of Energy/Operating Duration		
	Size	Weight	Power	Cost	Reliability
Solar Power	small (38.5cm^2)	light (0.7oz - 1.7oz)	0.5W min	$1.95 - $6.99	weather-dependent
RF	small (mm scale)	light (in mg)	Up to 0.43W	around $200	Still in early stages of testing
Piezoelectric	small (23.0 cm^2)	light	0.345W	Max around $34	everytime the wheelchair runs, it outputs power

When the team began brainstorming solutions, the first option discussed was using a combination of solar power, piezoelectrics, and RF power. The RF technology would supply power when the system is indoors, and the solar panels would supply power when it is outdoors. The piezoelectrics work for both indoor and outdoor applications.

However, this solution was not the one the team decided to pursue. There are multiple parts in the system which would make the building and debugging process more difficult and complex. The combined price of the harvesters was more expensive than other solutions. Specifically for the solar power aspect, the team would need to put time and resources into designing a mechanism to attach and hold up the solar panel. Lastly, there was no advantage to having the outdoor application since most individuals in the elderly care home did not spend time outside.

As piezoelectrics were researched, their disadvantages also outweighed the benefits for this application. For example, piezoelectrics generate the least amount of power since they would be attached to the wheelchair in between the wheel spokes. This means that when the wheel turns, the piezoelectric would be pushed back and forth. This would generate power when the wheels rotate, but it would also generate a significant amount of noise. The user of the wheelchair would not want to constantly hear the noise of a card-like material hitting the sides of the spokes. On top of that, having some material stuck in the wheel would be irritating. For these reasons the team chose not to power the system with a mix of the harvesters.

Instead of a combination, RF power is the sole harvester used to generate power to ensure that enough power was being supplied, the team decided on the components in the system and calculated the total power input.

3.2.2 Choosing the Energy Storage

For the application, the team needed to store the charge for at least 8 hours. The receiver board itself has a 50 millifarad on-board capacitor on it. However, the on-board capacitor was insufficient to hold enough charge to last the whole day. Therefore, a battery was chosen to store the charge, since that is their primary purpose. Furthermore, batteries also have a much lower charge/discharge rate, and thus are less volatile than their capacitor counterparts. An in-depth discussion into this decision can be found in Section 5.2.

3.2.3 Choosing the Sensing Module

The system that is attached to the wheelchair contains an accelerometer, gyroscope, and magnetometer and can log the data recorded. The team completed a value analysis for different microcontrollers, sensors, and data loggers. The following components were previously chosen: SparkFun Thing Plus - ESP32 WROOM [30], Sparkfun Open PIR [31], and Dataq Instruments Data Logger [32]. Members of the team have already worked with the SparkFun Thing Plus - ESP32 WROOM and Sparkfun Open PIR [30-31]. However, the data logger did not have the capabilities that were needed, such as the proper sensors or a sample rate of 100 hertz [31]. Also, the combined price of all the equipment was expensive, and with multiple parts, the complexity of the system increased. Therefore, this option was not the best solution possible.

The third option discussed contains the SparkFun OpenLog Artemis and a transmitter and receiver from Powercast. The Artemis contains sensors that log data for the wheelchair. The transmitter and receiver use RF power to charge the Artemis wirelessly. After speaking with residents of the Cherry Blossom Senior Living, it was clear that residents keep their wheelchairs in the same spot every night. Because of this, the RF power would be able to charge the device at night without the user having to plug it in. The device would then be ready for use the next day.

3.3 Final Product

The team decided to move forward with the alternative part that was found (the SparkFun OpenLog Artemis board), the lithium polymer rechargeable battery (to power the OpenLog Artemis board), the RF receiver modules (to power the lithium polymer battery), and a transmitter. Figure 3.1 below shows a block diagram of the team's final system. The PCB is represented in the diagram below by a block and shows how all the components are connected together.

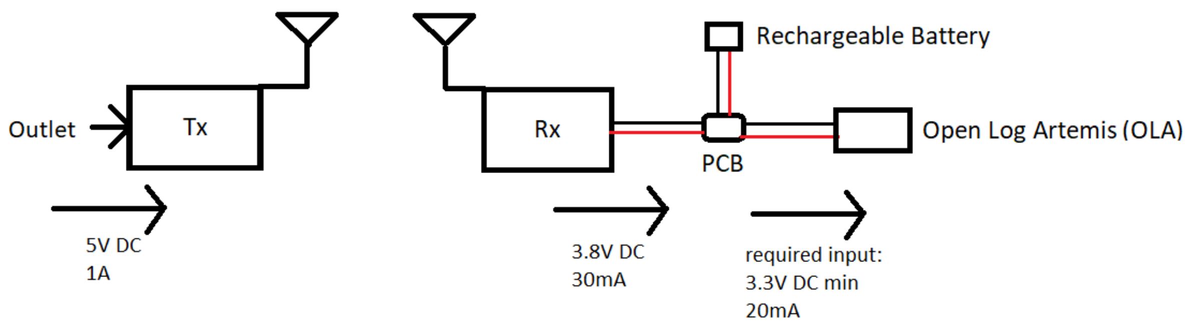

Figure 3.1: *Block diagram of the system.*

The solution that the team pursued is the third option discussed above, containing the SparkFun OpenLog Artemis board. This board is both compact and includes an accelerometer and a gyroscope for the final device. For current consumption, the board uses 20 milliamps of current in active mode, 80 microamps in sleep mode, and 18 microamps in deep sleep mode [17]. The input voltage ranges from 3.3 volts to 6.5 volts, and the maximum power necessary is 0.13 watts [17].

RF was chosen as the primary power source for this solution because it was found that it would supply sufficient power to the wireless wheelchair device. The Powercast modules have a frequency of about 915 megahertz [34-35]. The output voltage is 4.3 volts and the output current is 30 milliamps [34-35]. Although the Powercast modules were expensive, the advantages of this solution outweighed the disadvantages. As a result of all of these factors, the team decided to move forward with the SparkFun OpenLog Artemis and the RF transmitter and receiver modules from Powercast.

The system uses a lithium polymer battery. When the wheelchair is in the docking station, the RF harvester charges the battery. When the wheelchair is away from the docking station, the battery charges the OpenLog Artemis board.

The PCB was custom created by the team and it connects the components of the system together in parallel. It has 2 buses – one for power, and one for ground. Considerations for the battery and the PCB are discussed in greater detail later since they were reviewed later in the project timeline. Table 3.2 below shows the pros and cons of the final product, and consolidates the possible solutions considered by the team.

3.4 Chapter Summary

In this chapter, the design requirement details were explained for the dimension, cost, availability of energy, operating duration, and reliability. The decision-making process was outlined on the various options that were considered. Finally, the details of the final product were introduced including how each of the components were chosen.

Table 3.2: *Pros and Cons of the Possible Solutions*

Possible Solution	Pros	Cons
SparkFun Thing Plus - ESP32 WROOM, Sparkfun Open PIR, Dataq Instruments and RF Receiver Module	Easy to replace components Familiar with SparkFun Thing Plus - ESP32 WROOM and Sparkfun Open PIR Parts all met value analysis requirements well Receiver outputs 3.8 V at a distance of 4 inches between transmitter and receiver	The data logger doesn't have the capabilities needed Combined price is expensive Complex which may compound bugs Expensive (RF module costs $150) Limited places to attach to wheelchair Distance of transmitter and receiver cannot exceed 8 inches
SparkFun OpenLog Artemis and RF Receiver Module	**Contains the Accelerometer, Gyroscope, and Magnetometer** **Input voltage range 3.3V to 6.5V** **Current consumptions** - **20mA (active)** - **80 uA (sleep)** - **18 uA (deep sleep)** **Has active, sleep, and deep sleep mode** **Receiver outputs 3.8 V at a distance of 4 inches between transmitter and receiver**	**Expensive (RF module costs $150)** **Limited places to attach to wheelchair** **Distance of transmitter and receiver cannot exceed 8 inches**
Solar Power, Piezo (card or spring), RF Receiver Module	Works for indoor and outdoor applications 3 streams of wireless power being generated	Complex which may compound bugs Combined price is more expensive than other solutions (Piezo + RF cost) Attach solar panels and piezoelectrics while still being out of the way Expensive (RF module costs $150) Limited places to attach to wheelchair Distance of transmitter and receiver cannot exceed 8 inches

Chapter 4: Project Management

Before testing components and the circuit, the team faced several challenges. First there was an issue in figuring out if the team would run into any legality issues involving solar panels to generate power for the device. However, this was easily solved when it was found that the legality issues mainly applied to larger solar panel installations on roofs and company buildings. The smaller solar panels the team would most likely use for experimental purposes would not create any legality issues.

Another challenge the team ran into was scheduling an appointment at a rehabilitation center to interview users in wheelchairs. The team called several hospitals and rehabilitation centers, including UMass Medical, St. Vincent's Hospital, the Lutheran Rehabilitation Center, and Reliant Medical. The locations the team contacted were often very busy, and so it was difficult to schedule an appointment with any of them. Additionally, the team needed to get a wheelchair to use to test the wireless wheelchair device. One of the team members owned a manual wheelchair and brought it over to campus for the team to use for testing. Furthermore, the original data logger component the team was researching was not going to measure the exact data that the team needed. The team successfully found an alternative part that would measure the necessary data. Despite all of these challenges, the team had a project goal in mind, along with deadlines that the team hoped to achieve during the project timeline. The team's milestones are the following:

(1) Power the OpenLog Artemis board using the transmitter and receiver modules.
(2) Connect the OpenLog Artemis board to the lithium polymer battery.
(3) Connect every component in parallel.
(4) Attach the entire system to the wheelchair.

The system needed to be able to withstand the movements of the wheelchair. The receiver module must also continue to power the lithium polymer battery (which powers the OpenLog Artemis board).

4.1 Team Progress

The team created Gantt Charts to achieve these milestones and deliverables. The project ran for the entire school year, and the school year is broken up into four terms. Therefore, there was one Gantt Chart created for each term (A, B, C, and D term). The planned and actual Gantt Charts outlining the team's plans and progress are described below.

4.2 A Term Progress

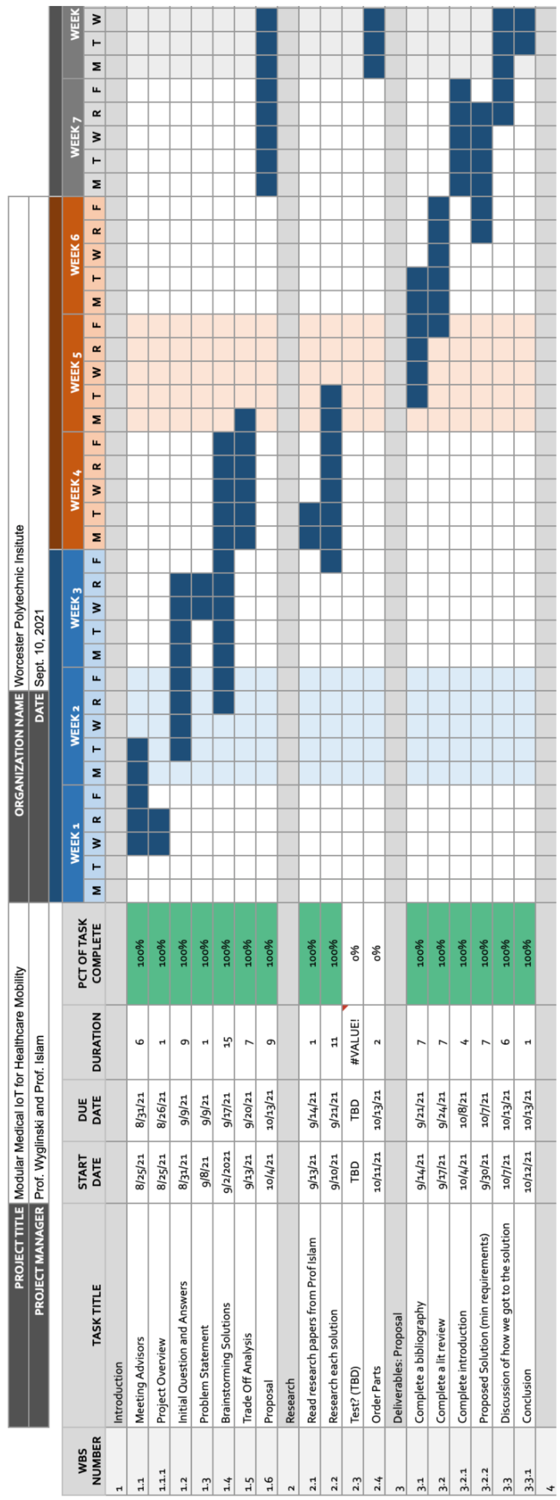

Figure 4.1: *Gantt Chart showing the MQP team's plan for the timeline for A term.*

The Gantt Chart shown in Figure 4.1 describes how the team expected the plan to go for the first quarter in the school year. The team spaced out all of the tasks so that there would be an adequate amount of time to complete each of them. In the first few weeks of the term, the team planned to meet with the advisors and discuss the project premises. Once this step was completed, the team wanted to finalize the purpose and problem statement of the project and to brainstorm possible solutions. Once the team had discussed some possible solutions, around halfway through the term, the team planned to complete a tradeoff analysis of these solutions to decide which one would work the best for the project. This involved researching more in depth into each of these solutions to figure out the pros and cons of each. Once a solution for the project was finalized, the team planned to complete a literature review and investigate other products that had similar features that the team wished to implement into their own project. This would aid the team in creating minimum requirements for the project, which would be done in the week following the completion of the literature review. These components – the literature review and the minimum requirements – would all be included in the proposal for the project, which the team planned to complete by the end of the term. In the last few weeks of the term, the team planned to work on and finalize the project proposal. There was also a consideration to test a variety of parts beforehand, but since the implementation of the project solution is expensive, the parts were bought for the final project only.

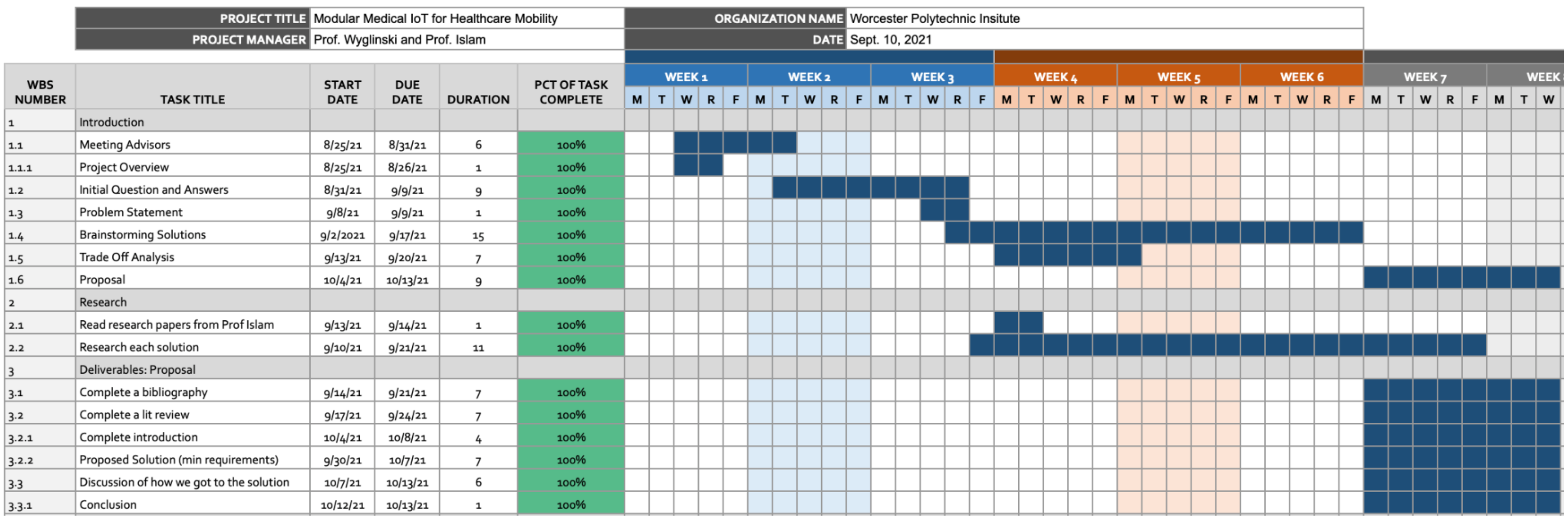

Figure 4.2: *Gantt Chart showing the MQP team's actual timeline for A term.*

The Gantt Chart seen in Figure 4.2 shows the true timeline. As the term went on, the team had to make slight changes to the plan as the project was being worked on. However, while the team had planned on brainstorming possible solutions around the same time as finalizing the problem statement of the project (shown in Figure 4.1), the team actually brainstormed possible solutions only after the problem statement and purpose of the project were completely finalized. This was because the team wanted to completely understand the project premises first before moving on to brainstorming possible solutions. A trade off analysis of the solutions was still completed at the time the team expected to complete one. The brainstorming and research conducted for the possible solutions took more time than the team had planned. This was because there was more time needed to consider the pros and cons of each solution, especially combinations or hybrids of those solutions. The proposal, including the literature review and minimum requirements of the product, was written after the team completed the background research into each of the possible solutions, as well as the final solution the team decided on. There were also additional tasks that came up during A term (not listed in the A term Gantt Charts) that the team wanted to look into in B term. These tasks are listed in the B term Gantt Charts.

By the end of A term, the team completed all tasks on the Gantt Chart of Figures 4.1 and 4.2. The team finalized the problem statement and purpose of the project, brainstormed, and researched possible solutions, and completed a tradeoff analysis of those solutions. The team also completed a literature review of prior art and decided on a final solution.

4.3 B Term Progress

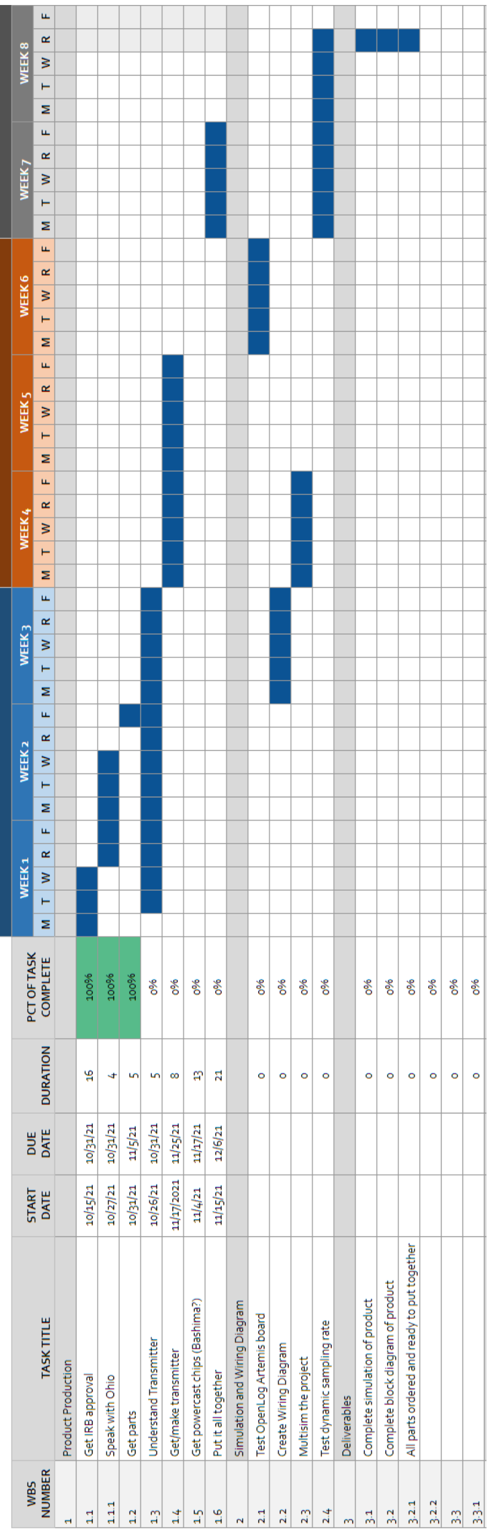

Figure 4.3: *Gantt Chart showing the MQP team's plan for the timeline for B term.*

The Gantt Chart shown in Figure 4.3 describes how the team expected the plan to go for the second quarter in the school year. As mentioned previously, some of the tasks listed in the B term Gantt Chart are tasks that came up during A term, but that the team decided to look into during B term. These are the first few tasks listed under Product Production in Figure 4.3, and the team planned to complete these tasks in the first few weeks of B term.

In the first couple of weeks of B term, the team planned to interview some residents of the Cherry Blossom Senior Living Home in Ohio. For this, the team must receive IRB approval. Since the team decided on using RF power for the wheelchair device, there was a discussion on where and how to get a transmitter-receiver system to test the RF energy harvesting. The team planned to understand how a transmitter worked to choose its properties that would best fit the needs of our product. The team also planned to order parts for the project in the first couple of weeks of the term. The team expected to have a physical diagram of what the project's circuit would look like. The team had completed some research previously on possible parts for the transmitter-receiver system of the project but were having some issues in getting the parts from the company. Therefore, the team planned to, around halfway through the term, see if one of the advisors of the project would have access to that part. After these steps were completed and the team received all of the necessary project parts, the team planned to test each of the circuit components and put them all together. The team would finalize a block diagram of the circuit by the end of the term.

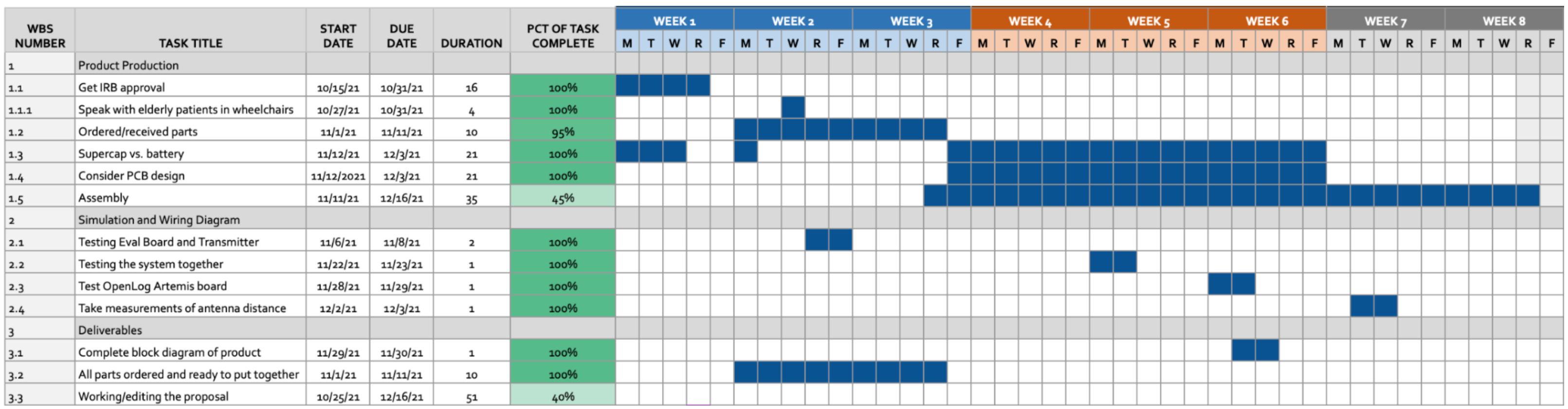

Figure 4.4: *Gantt Chart showing the MQP team's actual timeline for B term.*

The Gantt Chart shown in Figure 4.4 describes how the project went in B term. As the term went on, the team had to make slight changes to the plan as the project was being worked on, which can be seen in the new tasks added to the Gantt Chart in Figure 4.4. The team was able to get IRB approval for the interviews, so that occured in concurrence with the scheduled timeline. The team also ordered and received parts for the project near the beginning of the term as expected. One of the challenges the team faced was how to power the circuit when the wheelchair device was not in range of an RF transmitter. Therefore, the team investigated using either a supercapacitor or a rechargeable battery to power the wheelchair device when out of range of an RF transmitter. This new task took much longer than expected, and many considerations were made in this approach. The team needed more time to research in depth about the pros and cons of each of these options, and to discuss these options with the advisors as well.

In terms of parts, the team ordered and received all of the circuit components earlier in the term and could test each of those components throughout the term. The team was also able to start assembling the parts together earlier than projected. The assembly of the circuit parts continued throughout the term as edits were made to the circuit based on how well each component worked, and any changes the team needed to make to the circuit. The team also investigated a PCB design for the circuit to connect all of the components together. This began about halfway through the term and continued on until the last few weeks of B term. This was because the team needed to confirm what the design would look like, find suitable software to create it, and figure out how to create the PCB design using that software.

By the end of B term, the team completed all tasks on the Gantt Chart in Figures 4.3 and 4.4. The team received IRB approval and conducted interviews with senior living home residents, ordered and tested circuit components for the wheelchair device, and looked into using either a supercapacitor or battery for powering the device. The team discussed a design for the PCB to connect all the circuit components together. Along with that, the team assembled and tested the circuit via breadboard by the end of the term.

4.4 C Term Progress

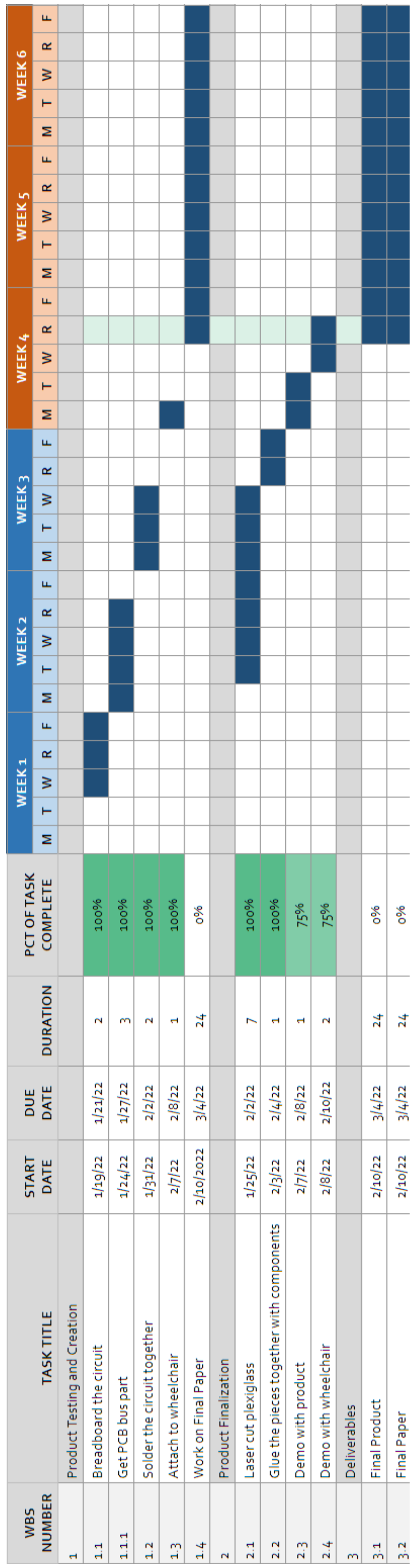

Figure 4.5: *Gantt Chart showing the MQP team's plan for the timeline for C term.*

The Gantt Chart shown in Figure 4.5 describes how the team expected the plan to go for the third quarter in the school year. The team planned to build the circuit on a breadboard again until the PCB bus part came. The team estimated that there would be a lead time of a couple of days for the PCB bus part and updated the Gantt Chart to reflect this estimate. Once the PCB bus part arrived, the team planned on soldering all of the circuit parts together. It was decided that it would be best to use plexiglass to create an enclosure for the system. Therefore, the team also planned on laser cutting the plexiglass and gluing the enclosure together simultaneously with the soldering. Once these steps were completed, the team planned on putting the circuit into the enclosure and attaching the enclosure to the wheelchair. The system would then be tested on the wheelchair and off the wheelchair to make sure it would work in both situations. The team set a deadline to have all of these steps completed by the end of Week 4 of the term. The team planned on working on the final paper and finalizing the wheelchair device in the last couple of weeks of the term.

WBS NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	Product Testing and Creation				
1.1	Breadboard the circuit	1/19/22	1/21/22	2	100%
1.1.1	Get PCB bus part	1/24/22	1/27/22	3	100%
1.2	Solder the circuit together	1/31/22	2/2/22	2	100%
1.3	Attach to wheelchair	2/7/22	2/8/22	1	100%
1.4	Work on Final Paper	2/10/2022	3/4/22	24	0%
2	Product Finalization				
2.1	Laser cut plexiglass	1/25/22	2/2/22	7	100%
2.2	Glue the pieces together with components	2/3/22	2/4/22	1	100%
2.3	Demo with product	2/7/22	2/8/22	1	75%
2.4	Demo with wheelchair	2/8/22	2/10/22	2	75%
3	Deliverables				
3.1	Final Product	2/10/22	3/4/22	24	0%
3.2	Final Paper	2/10/22	3/4/22	24	0%

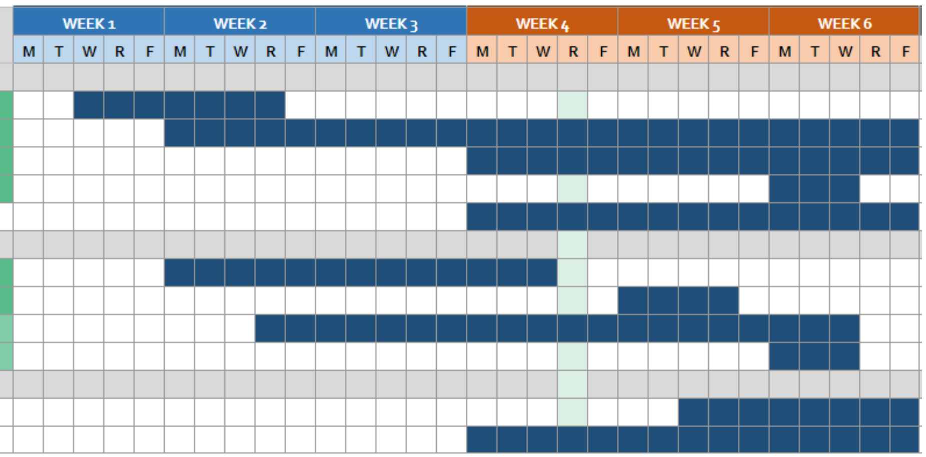

Figure 4.6: *Gantt Chart showing the MQP team's actual timeline for C term.*

The Gantt Chart shown in Figure 4.6 describes how the project went in C term. As the term went on, the team had to make slight changes to the plan as the project was being worked on. The team was able to build the circuit and start the process of laser cutting the plexiglass in the first couple of weeks of the term as expected. However, the amount of time it took to complete the laser cutting of the plexiglass took longer. The team wanted to schedule a consultation appointment first about laser cutting to understand how the laser cutting process worked, including what kinds of files would be needed to laser cut and how the software as well as the laser cutter worked. There was also a lead time for plexiglass after the team ordered it, and the team needed to re-laser cut some of the plexiglass pieces due to slight mismeasurements.

The processes of getting the PCB bus part and soldering the circuit together also took longer than expected. First, the team needed to ensure that the PCB design created in B term would work, and so a consultation appointment was scheduled to confirm this. Once it was confirmed that the PCB design would work, there was a lead time involved after ordering the PCB board. This lead time took several more days than expected, thus contributing to how long it took to get a final PCB bus part that worked. Additionally, the team had some issues with the PCB after it arrived, as the heat from the soldering would sometimes melt the traces in the PCB. This required the team to order more copies of the PCB bus and resolder the components onto the PCB. This incorporated more lead time into the team's schedule to get the new PCB buses, and more time in terms of resoldering the circuit onto the PCB bus. These factors contributed to increasing the amount of time needed to complete these steps, thus pushing back the deadline at which the team originally planned to complete testing of the product. Other tasks got pushed back due to these factors included gluing together the plexiglass enclosure and attaching the product to the wheelchair.

The team was able to have the plexiglass enclosure fully built, have all of the circuit components placed in the enclosure, and have the enclosure attached to the wheelchair by the end of the term. However, the team ran into some more issues with the PCB bus by the end of the term. Therefore, the team planned to order and receive a new PCB bus and complete testing of the device in the beginning of D term. Work on the final paper was done in the last few weeks of the term. By this time, the team would have all of the results and findings from the term and would be able to update the paper accordingly.

By the end of C term, the team completed all tasks on the Gantt Chart as seen in Figures 4.5 and 4.6. The team tested the circuit via breadboard to make sure it worked, and laser cut and assembled plexiglass to create an enclosure for the wheelchair device. The team also finalized and ordered a PCB bus to connect the circuit together and soldered all of the circuit components to the PCB bus.

4.5 D Term Progress

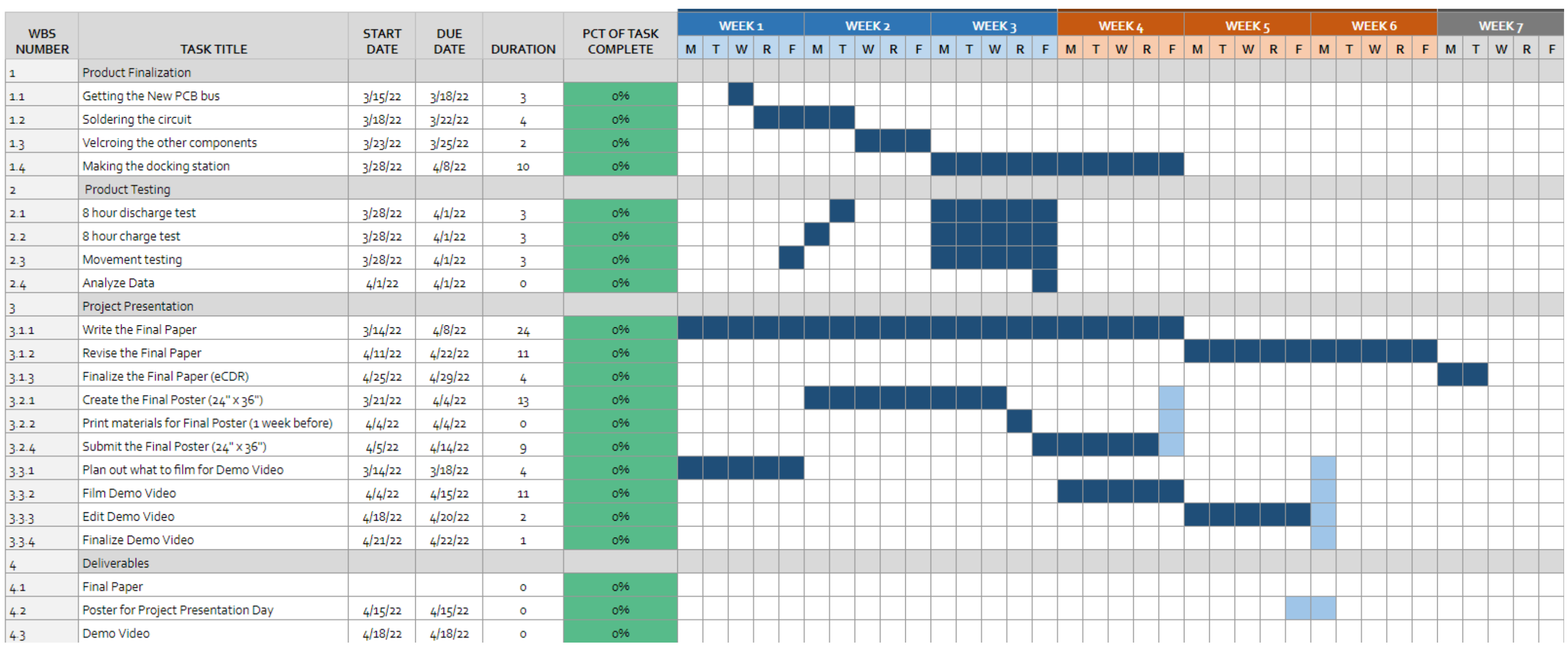

***Figure 4.7:** Gantt Chart showing the MQP team's plan for the timeline for D term.*

The Gantt Chart shown in Figure 4.7 describes how the team expected the plan to go for the fourth and last quarter in the school year. Since this was the last term of the school year and for the project, the team planned to work at least a few tasks at the same time every week. In the first few weeks of the term, the team planned on getting a new PCB bus that worked properly, soldering the components to the new PCB bus, and securing the circuit using double-sided tape in the enclosure. This was so that the system would not move around in the enclosure as much during testing. Velcro was considered as an option for securing the system, but ultimately was not chosen. The team also planned to complete the testing in the first few weeks of the term. These tests included testing the system on the wheelchair and analyzing the recorded movement data and testing the system for 8 hours (once for discharging the battery, and once for recharging the battery). The 8-hour tests were to confirm that the system would have enough power to work for 8 hours, and that the system would be able to fully recharge the battery in 8 hours. During the testing portion of the team's schedule, the team also planned to create a docking station for the wheelchair. The purpose of the docking station was for the user to be able to properly place the wheelchair such that the transmitter would not be affected by its placement, and that the transmitter would be properly aligned with the circuit's receiver to recharge the battery. Therefore, the docking station would have a spot for the transmitter, as well as spaces for the wheels of the wheelchair.

The team also planned on drafting out plans for the demo video and project poster and updating the final paper with the team's progress and results during this time. The project poster and final paper had deadlines of about one to two weeks before the end of the term, and so the team planned to start working on these tasks as early as possible. Overall, the team planned to complete work on the wheelchair device in the first few weeks of the term (resoldering, testing, docking station, etc.), then complete work on the project poster, video, and final paper in the second half of the term.

WBS NUMBER	TASK TITLE	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	Product Finalization				
1.1	Getting the New PCB bus	3/15/22	3/16/22	1	100%
1.2	Soldering the circuit	3/18/22	3/19/22	1	100%
1.3	Taping the other components	3/23/22	3/25/22	2	100%
1.4	Making the docking station	3/16/22	4/8/22	22	100%
2	Product Testing				
2.1	8 hour discharge test	3/28/22	4/1/22	3	100%
2.2	8 hour charge test	3/28/22	4/1/22	3	100%
2.3	Movement testing	3/28/22	4/1/22	3	100%
2.4	Analyze Data	4/1/22	4/1/22	0	100%
3	Project Presentation				
3.1.1	Write the Final Paper	3/14/22	4/8/22	24	100%
3.1.2	Revise the Final Paper	4/11/22	4/22/22	11	40%
3.1.3	Finalize the Final Paper (eCDR)	4/25/22	4/29/22	4	0%
3.2.1	Create the Final Poster (24" x 36")	3/21/22	4/14/22	23	100%
3.2.2	Print materials for Final Poster (1 week before)	4/15/22	4/19/22	4	100%
3.3.1	Plan out what to film for Demo Video	3/14/22	3/18/22	4	100%
3.3.2	Film Demo Video	4/11/22	4/13/22	2	100%
3.3.3	Edit Demo Video	4/15/22	4/19/22	4	100%
3.3.4	Finalize Demo Video	4/18/22	4/19/22	1	100%
4	Deliverables				
4.1	Final Paper	4/27/22	4/28/22	1	20%
4.2	Poster for Project Presentation Day	4/15/22	4/15/22	0	100%
4.3	Demo Video	4/18/22	4/18/22	0	100%

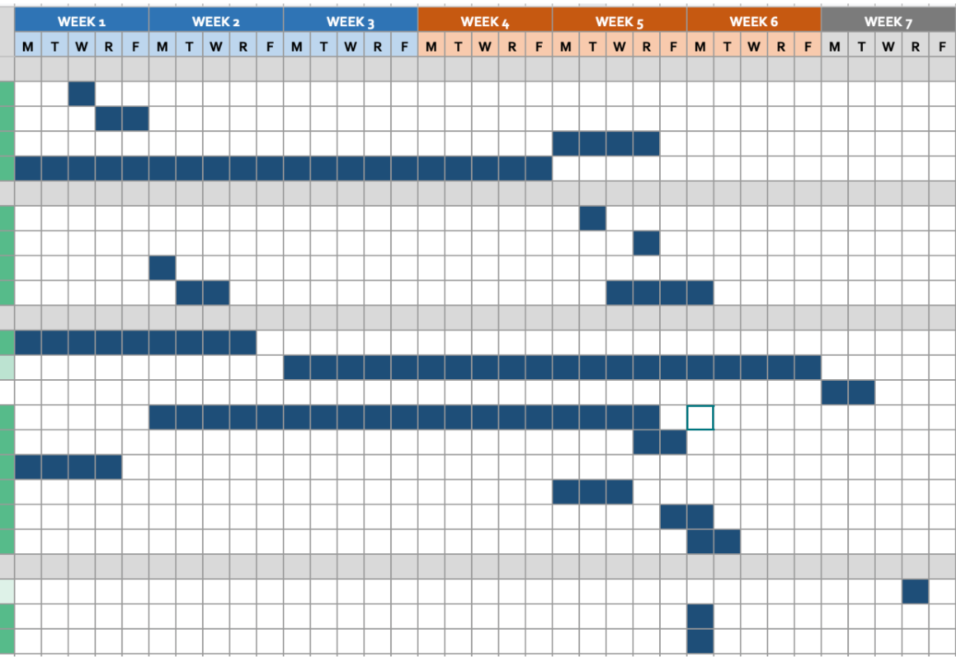

Figure 4.8: *Gantt Chart showing the MQP team's actual timeline for D term.*

The Gantt Chart shown in Figure 4.8 describes how the project actually went in D term. As the term went on, the team had to make slight changes to the plan as the project was being worked on. The team was able to receive a new PCB bus and re-solder all circuit components to it as planned and began working on the final assignments (final report, final poster, demo video) in the beginning of the term. However, the team also began working on the docking station in the beginning of the term, earlier than the team had planned. This was because the team knew that creating and finalizing the docking station would take a significant amount of time in addition to the other tasks the team had planned for the term (final report, final poster, demo video). Therefore, the team wanted to begin discussing the docking station with the advisors and finalize a design for it as soon as possible.

The team was also able to complete the movement testing and analyze its data earlier than planned. This was because the team received the new PCB bus quickly and was able to re-solder all circuit components to the PCB bus as planned. However, the team had to wait to complete the 8-hour charge and discharge tests of the battery because the team wanted to complete it when the device was attached to the wheelchair, and the wheelchair was at the docking station. Therefore, the team completed the 8-hour charge and discharge tests near the end of the term when the docking station was complete. The taping of components to the plexiglass enclosure also took place later in the term.

The editing process of the poster also took more time than expected. This was due to the majority of the feedback and edits being received and completed around halfway through the term. However, the team was able to submit the final poster on time for printing. The video was filmed and completed later than the team expected due to the team's focus on the final poster and docking station first. This was because the final poster had an earlier deadline to print it on time, and the docking station needed to be complete for the filming of the video.

Despite these challenges, the team was able to complete all tasks and deliverables on the Gantt Chart in Figures 4.7 and 4.8 by each of the tasks' respective deadlines. The team re-soldered all circuit components to a new PCB bus with thicker traces and tested the wheelchair device to obtain movement data and the 8-hour charge/discharge data. The team also completed the docking station and taped all circuit components to the plexiglass on time. Lastly, the team completed and submitted the final report, the final poster, and the final video for the project on time.

4.6 Chapter Summary

This chapter covered the different terms of the year and what the team accomplished in each term. The first term determined what the project would entail and what the team's minimal requirements and needs for the project will be. Background research on ways to complete these needs were also done that term. In the second term, the team completed more research on how the system can be created, and how it can electrically be feasible. In the third term, the team gathered the components and connected them to complete a system that can act as an activity monitor for wheelchair users. In the fourth term, the testing was completed, the project was demoed and completed along with a report and a video.

Chapter 5: Implementation, Results, and Analysis

This chapter covers the results the team gathered from running tests on the device and the implementation of the project. The assessments of the system included testing the voltage applied to the OpenLog Artemis at different distances, testing the capacitor that is on the Powercast Evaluation Board, testing the voltage before and after charging and discharging the battery, and tracking the movement of the wheelchair when the system was attached to it. An analysis of these results will also be discussed in this chapter.

5.1 Finalizing the Circuit

After each component of the team's system arrived, the team tested them individually to ensure they worked as expected. An important characteristic of using the transmitter and receiver as a power source was knowing what voltage is applied to the system at any distance. The closer the transmitter and receiver are, the stronger the signal is, and therefore, the stronger the voltage provided to the OpenLog Artemis. Figure 5.1 shows how the voltage applied to the OpenLog Artemis changed with respect to the distance between the transmitter and receiver. It was expected that as the distance increased, the voltage would decrease. Since the minimum operating voltage of the OpenLog Artemis is 3.3 volts, the testing determined that the distance between the transmitter and receiver cannot exceed 8 inches.

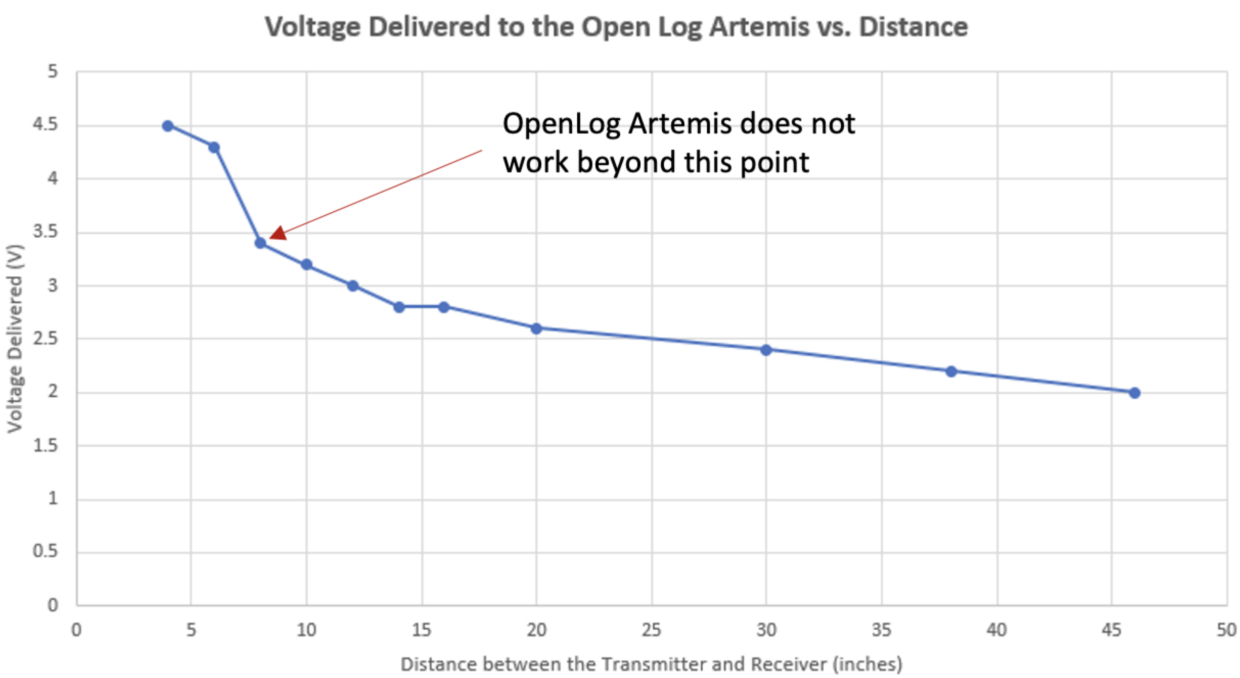

Figure 5.1: *Testing the voltage applied to the OpenLog Artemis as the distance increased.*

To optimize this transmitter-receiver connection further, a decision was made on the type of antenna used with the receiver. The specifications on the transmitter and receiver datasheets helped the team make an informed decision [34-35]. When the patch antenna was attached to the receiver, and the receiver and transmitter were adjacent, the voltage on the receiver from V_{out} to

Ground was 3.9 volts. When the dipole antenna was attached to the receiver in the same configuration, the voltage on the receiver from V_{out} to Ground was 3.7 volts. When the receiver was moved 30.5 inches away from the transmitter, the voltage with the patch antenna was 1.8 volts, and for the dipole antenna it was 0.53 volts. Clearly, in both cases, the patch antenna had a stronger connection, and therefore was generating more voltage. This was advantageous as it could keep the OpenLog Artemis charged for longer periods of time, as thusly was the team's ultimate choice.

5.2 Supercapacitor vs. Battery

There needed to be a way that this charge would be stored using a battery or a capacitor. For the application, the team needed to be able to slowly charge and discharge the SparkFun OpenLog Artemis consistently for at least 8 hours. The receiver board itself has a 50 millifarad on-board capacitor on it, so this capacitor was tested to see if it could hold the amount of charge needed. Figure 5.2 below displays the voltage across the on-board capacitor over time. As predicted, the voltage decreased and, after an hour, it never dropped below 3.3 volts. However, the amount of charge that the on-board capacitor can hold over time is not enough to charge the capacitor throughout the whole day. Therefore, the team referred to external sources to store charge.

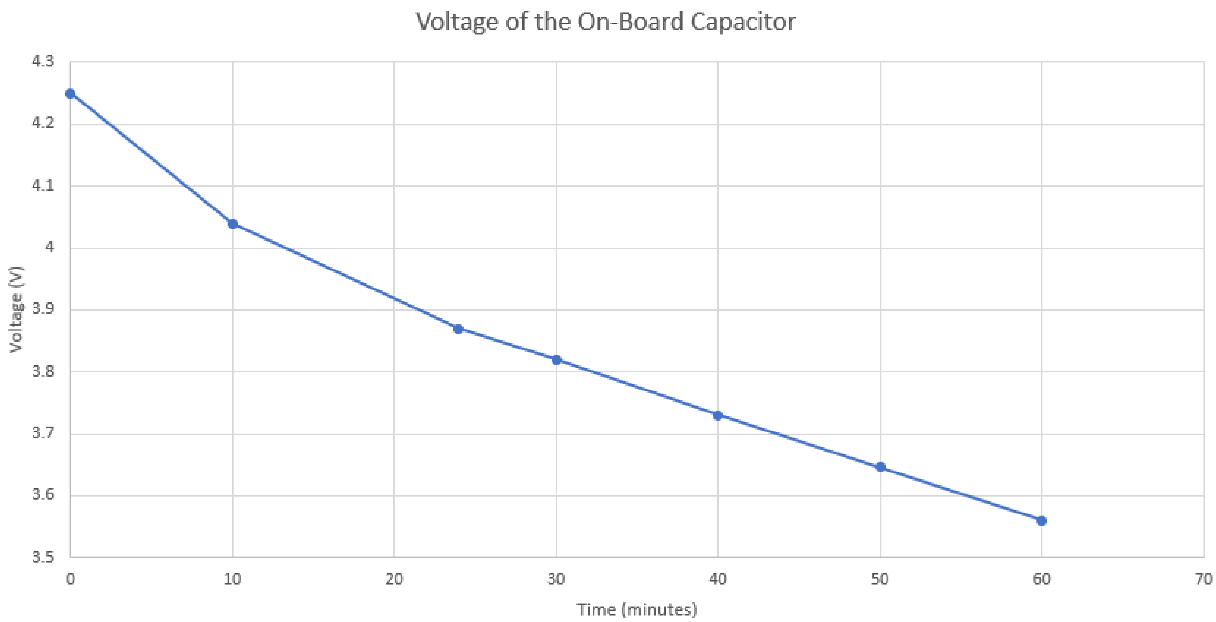

Figure 5.2: *Voltage across the on board capacitor as a function of time.*

The team had planned to create an RC circuit with a 576 ohm resistor and a 50 farad supercapacitor to store the charge that the OpenLog Artemis would use during the day. The input voltage of this RC circuit would be 4.2 volts, and the 50 farad supercapacitor would have a diameter of 18 millimeters. The supercapacitor would have connected in parallel to the resistor and OpenLog Artemis board. The team had planned to put this RC circuit onto a PCB board, which would then obtain its input voltage of 4.2 volts from the Powercast receiver evaluation board. However, after the team completed the calculations, when a minimum of 3.3 volts is applied to the OpenLog Artemis and the total charge that needs to be stored for 8 hours is 432 coulombs, then a 131 farad supercapacitor would be required. However, capacitors are more useful for applications with small time changes. They have a higher charge/discharge rate which would be an issue for this system. Additionally, to combat the charge/discharge rate, a DC-DC converter would be needed to balance out the voltage. This seemed impractical, since the OpenLog Artemis board was the primary load for the circuit, but more voltage would be drawn to the DC-DC converter and the supercapacitor combination. Therefore, the team decided to switch to batteries, since their primary purpose is to store charge. Batteries also have a much lower charge/discharge rate. By the team's calculations, an 80-160 milliamp hour battery was needed in order to meet the time requirement of powering the system for at least 8 hours. This was a reasonable battery to buy and was incorporated into the design.

5.3 Circuit Current Directionality

Switching between the receiver charging the battery and the battery powering the OpenLog Artemis was discussed to avoid the battery charging and discharging at the same time, which the team believed could cause it to malfunction. There were also concerns regarding the physical placement of these two components in the system. The LiPo battery only had two wire leads – one lead for ground, and the other lead for charging or powering another device. However in the team's system, the battery needed to be connected to both the RF receiver and the OpenLog Artemis board. The team felt that there was a need for a manual switch between the circuit components. However, the final wheelchair device needed to be an automatic to make it simpler for the user to function with it. So, the team looked into several components with automatic switching or current/voltage sensing characteristics. These components included transistors and MOSFETs (can be used to switch between circuits), relays (components that open and close circuits based on outside signals), multiplexers (multiple inputs with a single output), and diodes (which only allow current to flow in one direction).

The team ultimately decided to not consider any of these components due to them requiring an extremely high input voltage that the team's product does not have. After further research and discussion, the team realized that a separate electrical component was not necessary, and that the team's original plan – to directly connect a LiPo battery to the RF power and the OpenLog Artemis board – would not require an external current controller to function effectively. The current from the receiver to the battery is 30 milliamps and the OpenLog Artemis needs 20 milliamps to operate, so there is a difference in the current requirements. Also, the LiPo battery does not have a memory effect, which reduces the charge that the battery can hold. Without the transmitter nearby, the receiver would not be charging the battery. Therefore, due to these reasons, the pass-through charging is not an issue for the system.

5.4 Configuring the OpenLog Artemis

To obtain the data from the OpenLog Artemis, the settings of the OpenLog Artemis and the microSD card were configured. The Arduino Core was installed for Apollo3, the microcontroller on the OpenLog Artemis [36]. In order to get accurately timed data, the Real-Time Clock (RTC) had to be configured [17]. However, a characteristic of the OpenLog Artemis is that the RTC resets to 01/01/2000 if the reset button on the board is pressed when there is no power source connected to it [17]. It was also discovered that if the power source was changed, the RTC would also reset. For configuration purposes, the team used a laptop, the receiver, and the rechargeable battery as power sources for the OpenLog Artemis. A USB-C connection cable was used to power the OpenLog Artemis with a laptop [37]. During testing, the reset button was needed at times to wake up the data logger or to debug the system. As a solution, the OpenLog Artemis can be connected to two power sources (laptop and battery) temporarily to switch the power source without changing the settings [17].

5.5 System Testing

Once the team understood how the components would fit together in a circuit, the team pursued one of the primary goals of making sure that the system ran for a full working day. The team determined a full working day to be around 8 hours based on the responses from the survey from the senior living home. The team decided it would be best to test the system, especially the battery and the OpenLog Artemis, to see if it is feasible. The circuit was first assembled using a breadboard. The team attached the oscilloscope to the connections between the OpenLog Artemis and the battery to monitor the current and voltage running through the circuit at any given time. This was done over 8 hours, with the team taking shifts to watch the circuit for any changes in current or voltage, or the point when the voltage went past the 3.3 volts minimum needed to run the OpenLog Artemis. During testing, the battery started with about 3.8 volts to power the OpenLog Artemis. At the end of the day, the battery was down to 3.6 volts, which is well above the 3.3 volts minimum. This means realistically that the system can run for more than 8 hours, which is an advantage since that provides the user with a safety buffer. This was repeated with similar results, showing that the range of charge left after use during the day is reproducible. Figures 5.3 and 5.4 below show the discharging and charging of the rechargeable lithium battery over 8 hours.

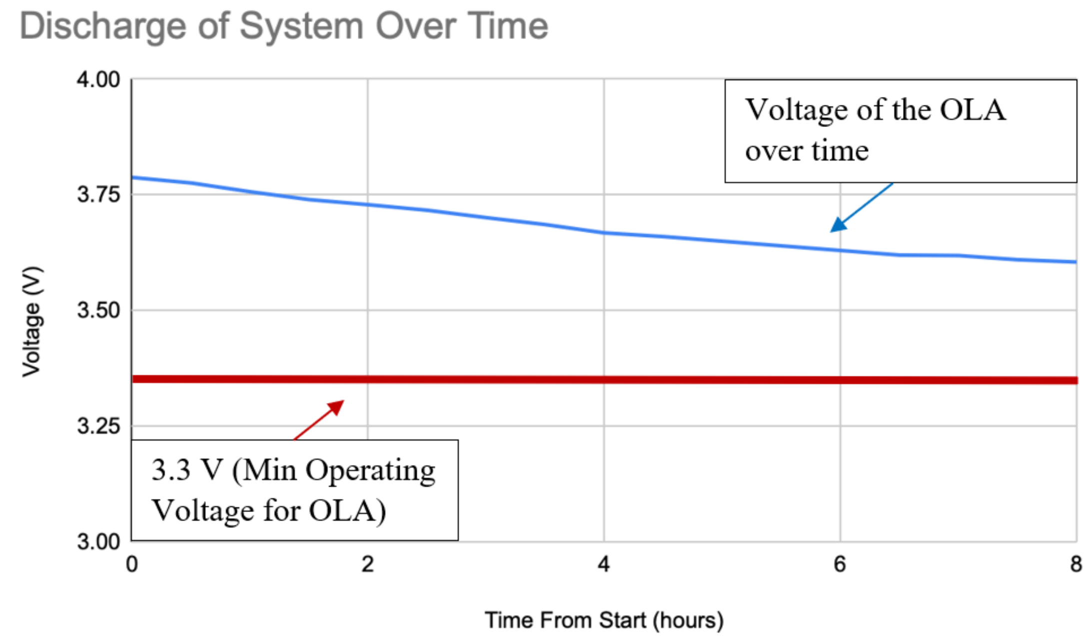

Figure 5.3: *Discharging of rechargeable lithium battery over 8 hours.*

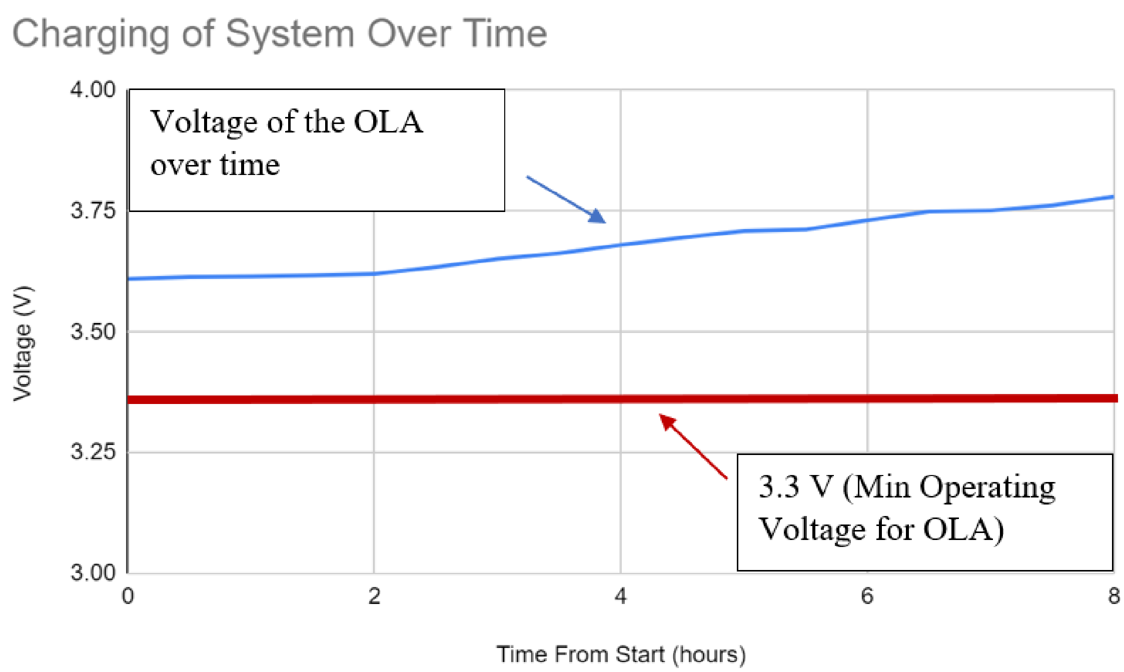

Figure 5.4: *Charging of rechargeable lithium battery over 8 hours.*

However, during testing the team discovered that the transmitter turns off every 30 minutes and has to be reset using the reset button. Although this was not ideal, it was manageable. After speaking with a Powercast representative, the team realized that a RF-to-DC evaluation board would need to have a system on chip (SOC) circuit that would be recognized by the transmitter, which the company offers. In retrospect, the team should have bought this board instead. However, there is no such advertisement or disclaimer listed anywhere on the Powercast website, so the team had no way of knowing about this prior to testing. As a future implementation, this board could be bought instead of the one that is currently in place, which is an easy fix for this issue. As for the testing, since the team was always monitoring the circuit, as mentioned before, the team just turned the transmitter back on whenever it turned off.

5.6 Movement Testing

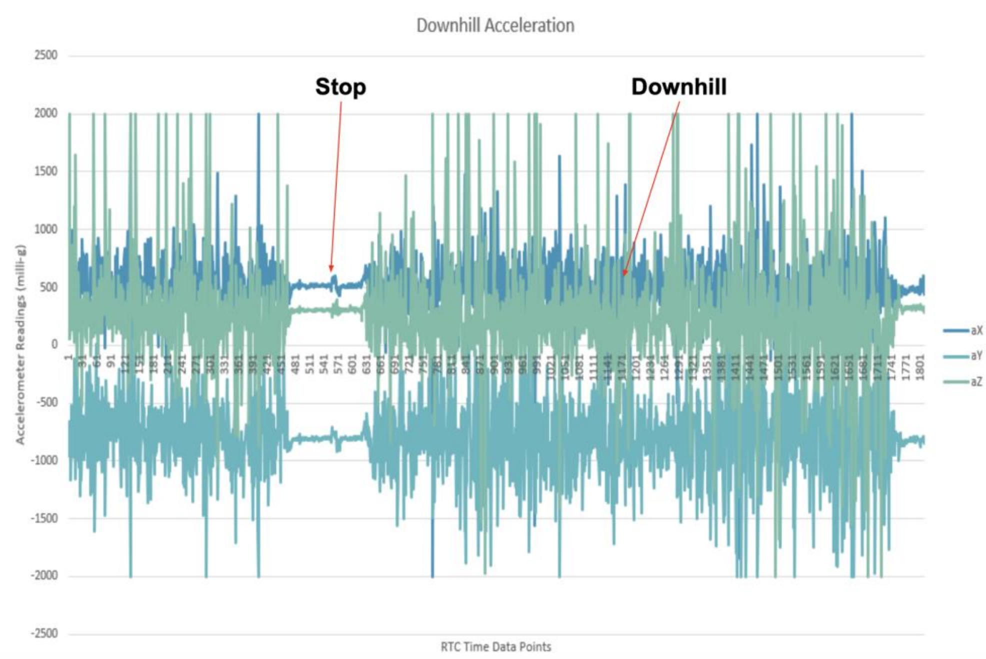

Figure 5.5: *Accelerometer readings when the wheelchair accelerated downhill.*

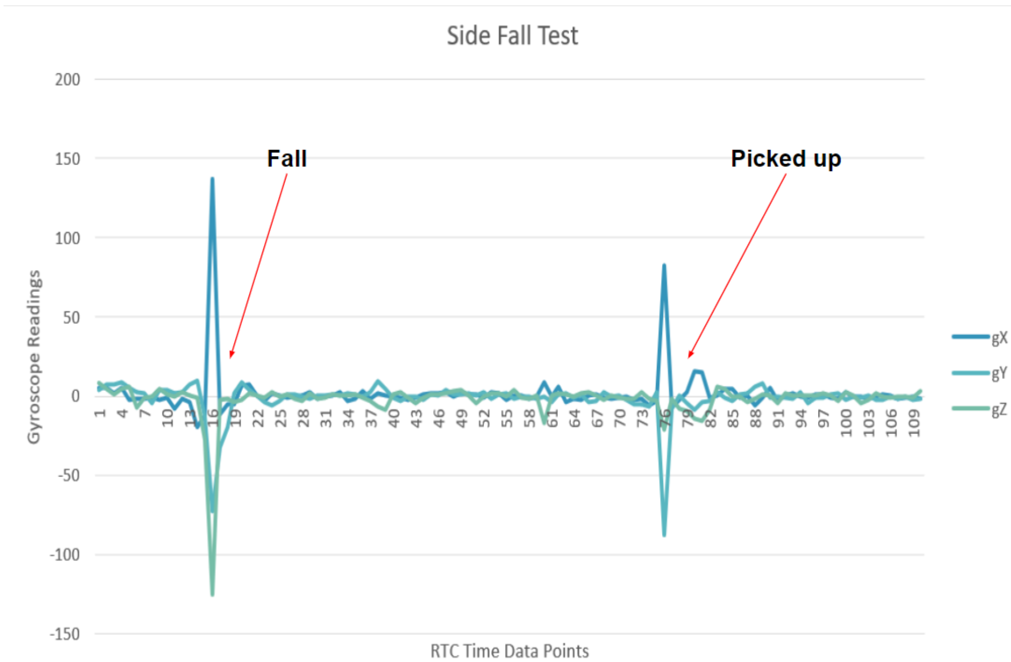

Figure 5.6: *Gyroscope readings when the wheelchair fell on its side.*

To test the accelerometer, the wheelchair with the device was taken on a test run around campus. The team tested the wheelchair on different surfaces, including cobblestone and concrete, as well as different altitudes and directions, such as uphill and downhill. Figure 5.5 shows this downhill acceleration on concrete, which shows many different features including how fast the team was accelerating. At a certain point during testing, the team had stopped to make some assessments. This can be seen in the graph when there is a distinct pause in the data collection at around 541-571 data points, which amounts to 54 seconds in the team's testing where each data point occurred within 1/10 of a second after the other. This is the raw and unfiltered data, but the pause shows the baseline, and that the average of the data points when the wheelchair is not paused will still be above the baseline, showing that this information is still valuable and informative. The team also used the features of the gyroscope to test fall detection. This was done by toppling the wheelchair on its side. The first spike shows that fall that is indicated in a clear way on the graph. The second spike indicates when the wheelchair was lifted up off the ground. This is a good application of the gyroscope, as the graph provides a clear indication that the wheelchair user is in trouble since the wheelchair ideally does not rotate.

5.7 Custom Designing

Chapter 5.7 discusses the designs of the PCB, plexiglass enclosure, and the docking station, as well as how the team created each of these parts. This chapter also discusses the challenges faced by the team when finalizing these parts, and how the team resolved these challenges.

5.7.1 Custom PCB Design

After the components were collected and tested, there needed to be a way to place them in a parallel circuit together. The team designed a PCB on Eagle as it was on the breadboard: with two buses, one for power and the other for ground. There are three rows for each of the three components of the system - the receiver, the battery, and the OpenLog Artemis board. In this way, each of these three components are connected in parallel with one another, meaning they will all run at the same voltage of ~3.7 volts. When the PCB was available, the team soldered the components to it.

Figure 5.7: *Picture of PCB used to connect components of the wheelchair device.*

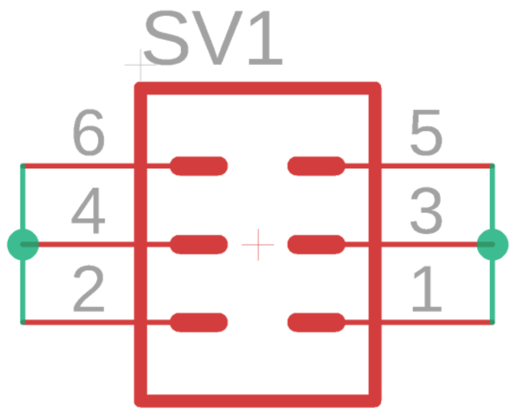

Figure 5.8: *Schematic of the PCB.*

Another challenge the team encountered involved the OpenLog Artemis board not turning on when all circuit components were connected. Each of the components of the circuit were measured and demonstrated that they were working, therefore it was concluded that the PCB bus was not working properly. On closer inspection, it was found that the connections were very thin. Due to the amount of soldering done, the PCB bus connections needed to be thicker to prevent the connections from breaking. Therefore, a new copy of the PCB bus was created with thicker traces. The team soldered the circuit components to the new PCB bus, and the circuit began working again. Figures 5.7 and 5.8 show a picture and schematic of the final PCB used to connect the components of the wheelchair device.

5.7.2 Plexiglass Enclosure Design

Post completion of the circuit and the testing, design choices were made regarding how the circuit would be housed. It was decided that a plexiglass box would be the best option because it would protect the system, the circuit can still be seen from inside the box, it is visually appealing, and it can be easily mounted to the wheelchair. One choice that was discussed was whether to have the receiver antenna on the outside or the inside of the box. The concern was whether the transmitter would be able to communicate with the receiver with the plexiglass piece between it. This was tested and the RF signal successfully passed through with no problems.

The lengths of the components were measured, and the team decided that a 8” by 6.5” by 2.5” box would be sufficient. Firstly, a schematic for the enclosure was made, as shown in Figure 5.9, with six sides and hinges for the top.

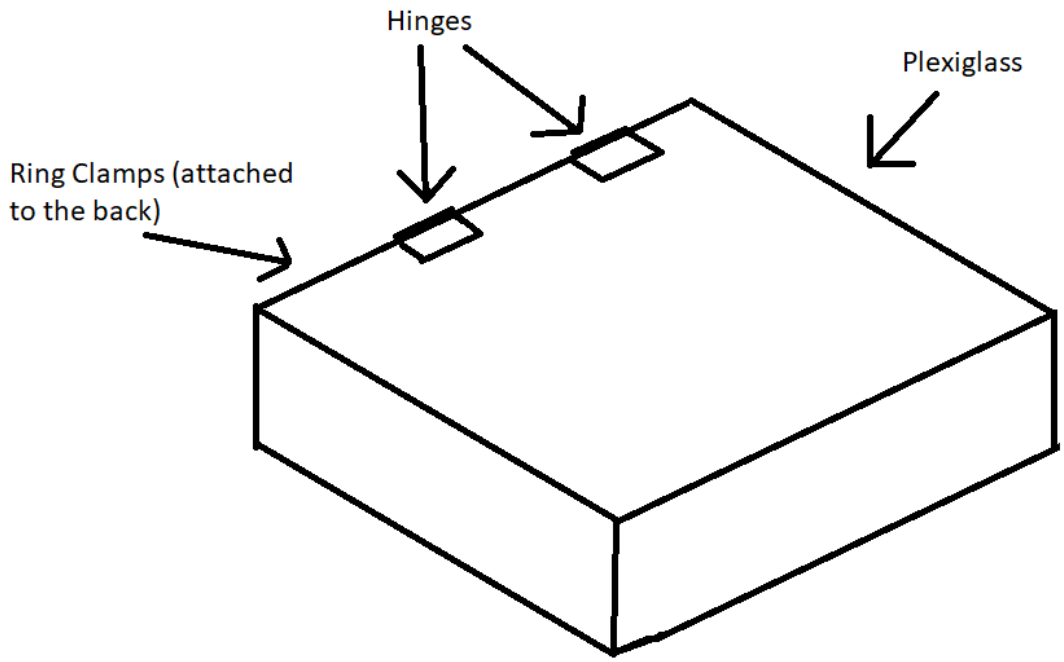

Figure 5.9: *Schematic of the plexiglass design.*

The six plexiglass pieces were created in Inkscape and were cut out using a laser cutter. In order to access the circuit inside, hinges were added to the top piece of the box so that the lid could open and close. The receiver was attached to the bottom of the box using standoffs. To attach the box to the wheelchair, two ring clamps were glued to the back of the box. The ring clamps were attached to a bar under the wheelchair. This way the system is out of the way of the wheelchair user. It was also closer to the transmitter, which means that the receiver voltage was maximized. Figure 5.10 below shows this circuit housed in the plexiglass.

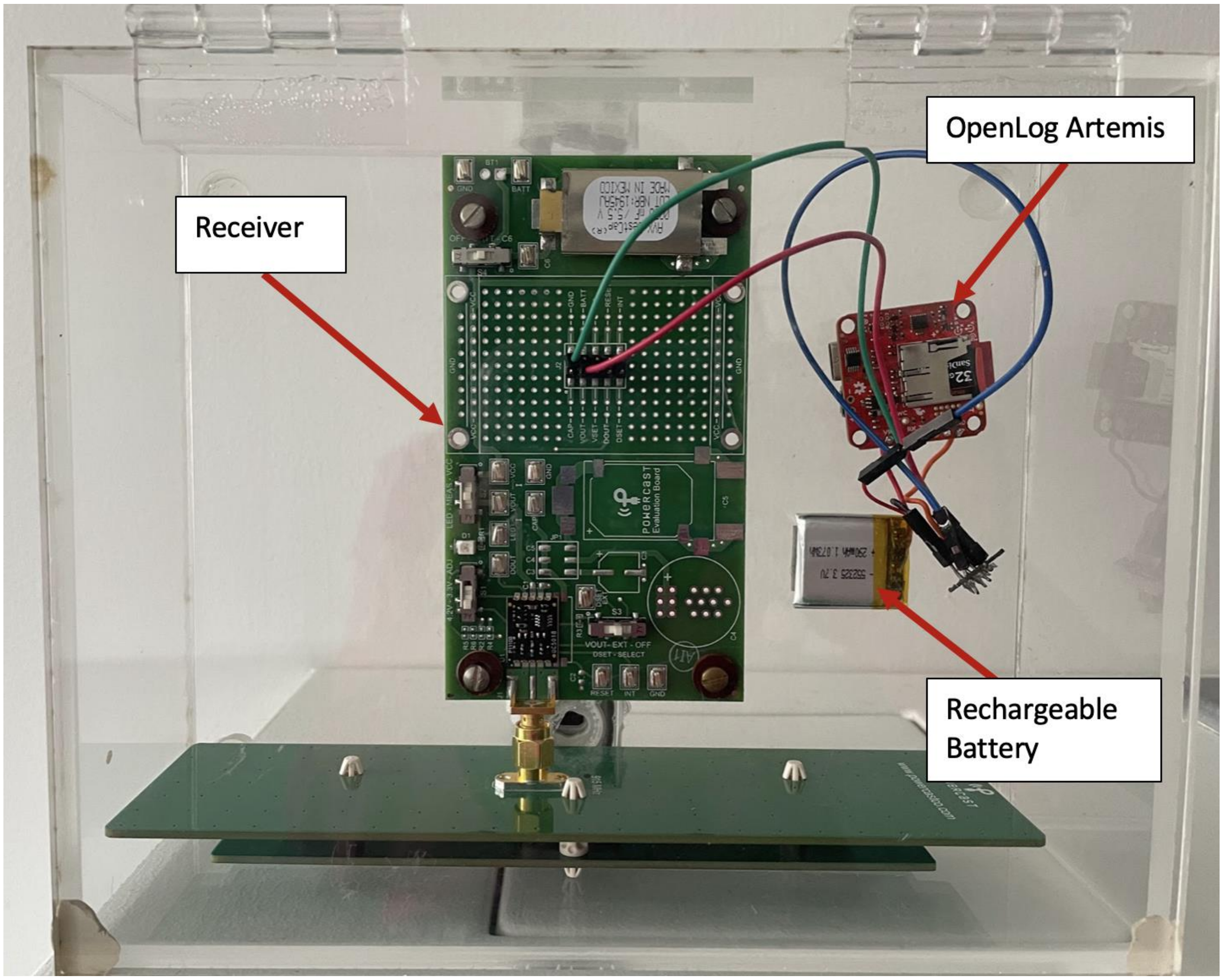

Figure 5.10: *Image of wireless wheelchair system housed in plexiglass.*

5.7.3 Docking Station

After the completion of the wheelchair, the team decided to create a docking station that was able to have the transmitter on the ground in one place that would not be run over by the wheelchair user. Furthermore, the transmitter and the wheelchair alignment is always the same, since the transmitter and receiver work best when directly aligned over another. For these reasons, the members felt that the docking station was a necessary addition to the project. However, there was much contention regarding how to complete it. The team decided that a particle board would be used to create the docking station, after considering cardboard, rubber, and 1.5" wood. Out of these options, particle board was the most easily accessible, durable, and easy to cut. The team created a platform 1.5" off the ground, with two slits in it for the wheels to slide in. The wheels stop at the midway point of the station since the wheels can scuff the walls if they make contact with it. The transmitter is also embedded in the docking station, and the wheel stops ensure that the transmitter and receiver are always aligned. The docking station was also painted black for aesthetics. Figure 5.11 below shows the wheelchair with the docking station in its final form.

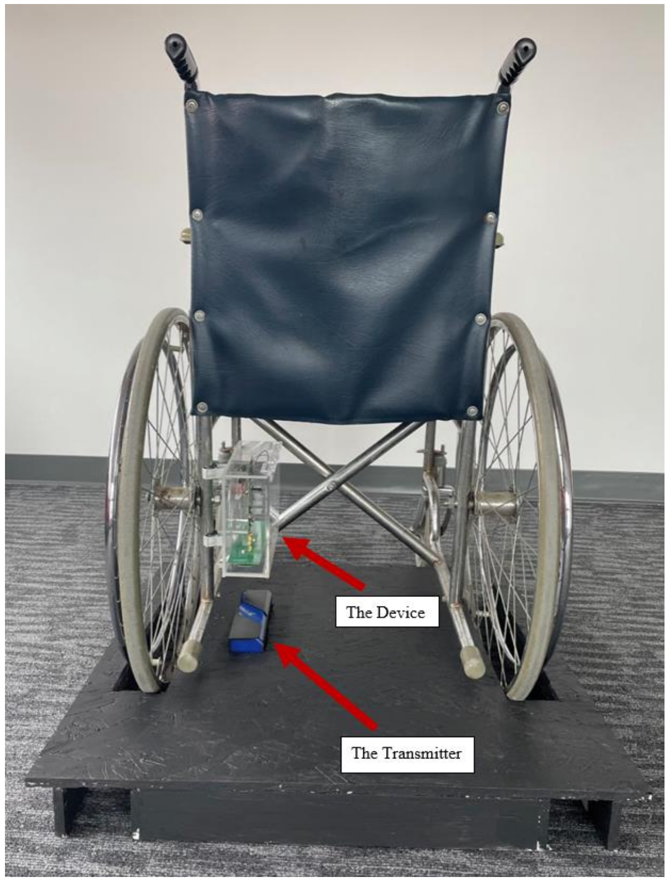

Figure 5.11: *Image of the system attached to the wheelchair and parked at the docking station.*

5.8 Chapter Summary

This chapter discusses the results from testing the team's product, the analysis of these results, and the parts used for the final solution of the wheelchair device. This chapter also discusses the challenges faced by the team when developing this product. Chapter 5.1 discusses how the team finalized the circuit used for the wheelchair device, and how the team optimized the transmitter-receiver connection. Chapter 5.2 discusses how the team decided between using a supercapacitor or a battery to power the team's product, and the reasons for the team's decision. Chapter 5.3 discusses how the team made sure there would be no issues in the product in terms of current directionality. Chapter 5.4 discusses how the team configured the OpenLog Artemis board. Chapter 5.5 and 5.6 discuss the tests the team conducted on the wheelchair device, including 8-hour tests and movement testing. Chapter 5.7 discusses the designs of the PCB, plexiglass enclosure, and the docking station, as well as how the team created each of these parts.

Chapter 6: Conclusion

The current fitness tracking market does not offer relevant statistics to people who use wheelchairs, so the team built and implemented a product that can act as a fitness device for wheelchair users. The team successfully created a low-power, wireless sensing system that records data in terms of the surrounding environment, movement, and fall detection, keeping in mind the ease of use for those that are disabled. This product is powered by RF energy harvesting, which involves an antenna receiving electromagnetic waves from a transmitter at a specific frequency and converting those waves into DC voltage. The wheelchair device includes an OpenLog Artemis board, which has a gyroscope and a triple axis accelerometer, to record motion data in three dimensions. A rechargeable battery was added to keep the wheelchair device powered throughout the day, when the user is out of range of an RF transmitter.

In terms of future applications, the system can use a centralized transmitter instead of the current transmitter. With this improvement, the size of the transmitter can be larger, and it can be placed near multiple rooms. This way, more rooms can have access to one transmitter and the range of the transmitter is less localized [38]. Another implementation to work on in the future is using a dynamic sampling rate on the OpenLog Artemis board [39]. A lower sampling rate will decrease power consumption. When implementing a dynamic sampling rate, the system should recognize when the wheelchair user is not moving, and thus decrease the sampling rate accordingly. This would help the system save power. When the wheelchair user starts to move again, the sampling rate would increase to ensure sufficient data collection.

From this project, it was concluded that this device has potential to be used as a fitness tracker for wheelchair users. An important part of creating this type of device was researching energy harvesting techniques and deciding to use RF signals to generate power. Users can utilize this device during the day without worrying about the device running out of power and can easily recharge the device during the night. The wheelchair wirelessly charging means that the device can be hands free and does not require the user to plug anything in. It removes the hassle of wired charging and simplifies the process for wheelchair users. Currently, this type of modular product does not exist on the market, therefore leaving those in need of such a device with no way of knowing what their daily activity is like or whether they are getting enough activity that they need. Overall, this device helps wheelchair users and their caretakers to analyze the recorded data, so that they can better understand their movements and activities throughout the day. This solution is also cost effective, so those that cannot afford smart powered wheelchairs can afford and attach this to a manual wheelchair that they already use. This can improve the quality of life for the user and better their health by providing them with statistics of their movement, environment, and if a fall occurs.

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Chapter 8: Appendices

Appendix A: Interview Questions and Script for Cherry Blossom Senior Living Residents

Note: The number of the IRB approval form for this interview is IRB-22-0165.

Intro: Hi! We are students at WPI working on our capstone project. We wanted to get a better idea of wheelchair use to create a device that attaches to wheelchairs. Thank you for participating. We really appreciate it!

We have about 10 questions to ask. Your participation is completely voluntary, and all of your answers will remain confidential/anonymous. If there is any questions you do not want to answer, that is totally fine, just let us know. Do you have any questions before we get started?

Interview Questions:

- Do you operate your wheelchair by yourself or does a nurse/someone assist you?
- On a typical day, describe your movement (how often do you use your wheelchair?)
- What parts of the wheelchair are used the most?
- How often would you say you are outdoors during the day? Indoors?
- Is there a spot where you put your wheelchair at the end of each day?
- We want to create a device that logs movement data, would you be interested in using this?
- Where on the wheelchair could we attach a small device so that it is out of the way of everyday activities?
- What additional capability would you like to have in your wheelchair?

If time allows:

- Do you experience issues with accessibility during the day?